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Report 3

Water Resources of the Upper Nottawasaga River Drainage Basin

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WATER RESOURCES
REPORT 3

Water Resources of the Upper Nottawasaga River Drainage Basin

By
U. Sibul and A. V. Choo-Ying

ONTARIO WATER RESOURCES COMMISSION
DIVISION OF WATER RESOURCES

TORONTO ONTARIO

1971

PREFACE

Basic inventory and use information is fundamental to the development and management of any resource. To this end, drainage basin surveys are undertaken by the Ontario Water Resources Commission to evaluate surface- and ground-water resources in the province.

This report, the third in a series, draws on published records and reports, together with field data collected during 1968, to present interpretive information on geology, water resources and water uses for the upper Nottawasaga River drainage basin.

K Symons

Toronto,
February 4, 1972.

K. E. Symons, Director,
Division of Water Resources.

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WATER RESOURCES OF THE UPPER NOTTAWASAGA RIVER BASIN

ABSTRACT

A study of the occurrence, distribution, quantity, and quality of water in the basin was undertaken as part of a continuing program of river basin water-resources investigations conducted by the OWRC in the province. The upper Nottawasaga River basin was chosen for study because of water-use conflicts caused by withdrawals from streams, and because of increased water demands created by urbanization at Alliston, Beeton, and Tottenham.

Field work involved geologic mapping, streamflow measurement, surface- and groundwater sampling, and the installation of 21 piezometers and two water-level recorders on large-diameter observation wells.

The report deals briefly with geography and geology, but presents detailed discussions on the distribution and yield of aquifers, streamflow characteristics, water quality, and water use. A hydrologic budget for the 1968 water year is also presented.

The best bedrock aquifers are located in dolomites of the Amabel Formation in the western part of the basin, and four extensive aquifers have been identified in the overburden in the central and eastern parts. Development of these aquifers is recommended.

During the 1968 water year, precipitation in the basin was estimated to be 33.2 inches. Streamflow out of the basin was equivalent to 12.7 inches, of which 7.8 inches was calculated to be direct surface runoff and 4.9 inches was attributed to base flow. Evapotranspiration was estimated to be 23.0 inches, with an imbalance of 2.5 inches in the water-budget equation. Evapotranspiration was estimated by the water-balance, Thornthwaite, and Konstantinov methods; the latter method yielded the more probable monthly values.

Both surface and ground waters are of calcium-bicarbonate type. The chemical quality of most of the 39 sources sampled during the survey was satisfactory for domestic and irrigation uses.

Surface-water withdrawals are mainly for irrigation, while ground water is used for municipal, rural domestic, and stock purposes. Adequate supplies of acceptable quality surface and ground water are available for most uses. Seasonal water shortages do occur and may be alleviated by improved water-management practices. Particular attention is directed to the local opportunities for developing ground water to resolve surface-water conflicts and shortages.

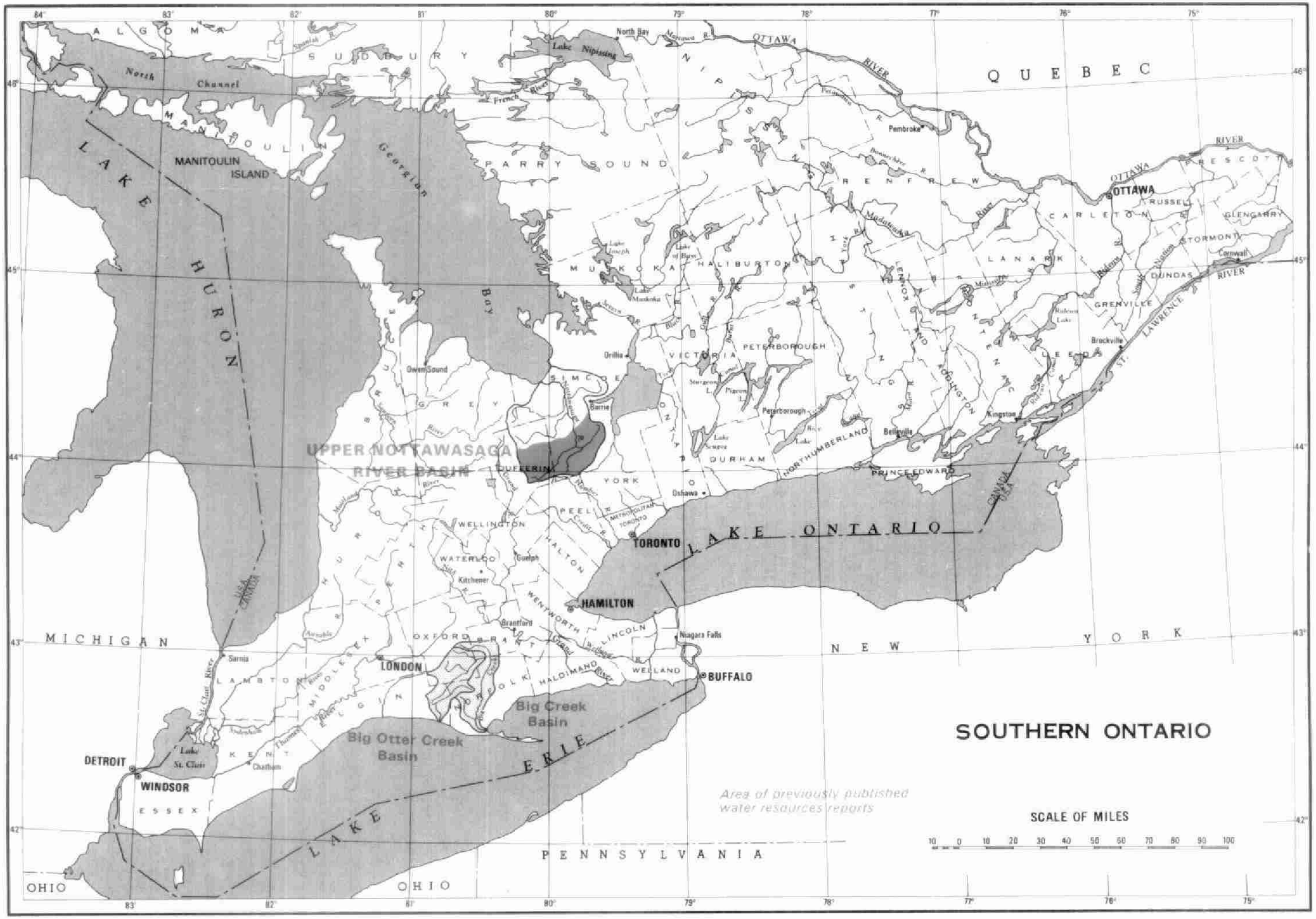


Figure 1. Location and extent of Upper Nottawasaga River basin.

INTRODUCTION

Purpose and Scope of the Investigation

The objective of this report is to present basic water-resource information for the upper Nottawasaga River drainage basin. The report is intended for the guidance of individuals, groups, and agencies in the development of the resource to satisfy independent and collective interests. The assessment of water resources in this basin was prompted primarily by increasing demands for water for irrigation of tobacco, potatoes, and sod, which are grown on the sand plain adjacent to the Nottawasaga River and some of its main tributaries in the basin.

This investigation commenced in 1968 and was limited to one field season. Only that part of the Nottawasaga River basin located upstream from the stream gauge at Baxter was chosen for the investigation. This region is referred to in this report as the "upper Nottawasaga River drainage basin" (or simply as "the basin").

The report presents and evaluates water-resource data in terms of quantity, quality, occurrence, and distribution of water in the basin.

Field investigations were made of surficial geology, streamflow, ground-water levels, water quality, and water use. Seven piezometer nests and two automatic recorders on wells were installed. A recording rain gauge was used to obtain precipitation data at the two observation-well sites. Available streamflow data were supplemented with periodic streamflow measurements at selected sites in the basin.

The amount of quantitative and qualitative data varied for each specific subject in the report. For example, data pertaining to the hydrologic budget of the basin are sparse and limit the depth of analysis. Consequently, only a simplified equation of the budget is calculated. Data available on surface water are copious and therefore the treatment of this subject is more thorough.

Location and Extent of the Basin

The upper Nottawasaga River drainage basin is in south-central Ontario between the longitudes of 79° 35′ and 80° 16′W and the latitudes of 43° 56′ and 44° 18′N, and is about 30 miles north of Toronto (Figure 1). It is essentially rectangular in shape; approximately 33 miles long in an east-west direction and 14 miles wide in a north-south direction.

The Nottawasaga River, part of the Georgian Bay drainage system, flows out of the study area at Baxter and follows a northward course until it discharges into Nottawasaga Bay at Wasaga Beach. The main tributaries of the Nottawasaga River in the study area are: Boyne River, Sheldon Creek, and Innisfil Creek with its tributaries of Beeton and Bailey creeks. The total drainage area of the basin is approximately 470 square miles and contains portions of the following counties and municipalities:

County	Municipality	Area within the Basin	
		(%)	(sq. mi.)
SIMCOE		19	294
	Adjala Township	88	65
	Alliston Town	100	< 2
	Beeton Village	100	< 1
	Cookstown Village	100	< 1
	Essa Township	52	49
	Innisfil Township	25	37
	Tecumseth Township	88	86
	Tosorontio Township	29	22
	Tottenham Village	100	< 1
	West Gwillimbury Township	45	32
DUFFERIN		30	171
	Amaranth Township	19	19
	Melancthon Township	16	18
	Mono Township	91	98
	Mulmur Township	34	34
	Shelburne Village	100	< 2
PEEL		< 1	4
	Albion Township	2	4
YORK		< 1	< 1
	King Township	< 1	< 1

There are five main population centres in the basin, the Town of Alliston and the villages of Beeton, Cookstown, Shelburne, and Tottenham.

Previous Investigations

Past investigations in the basin have dealt with two main topics: conservation and general natural-resource studies, and geologic and land or soil classification studies. A comprehensive report by the Ontario Department of Energy and Resources Management (1964) deals with land, forestry, wildlife, and recreation.

The Ontario Water Resources Commission (OWRC) has been involved in a number of local municipal investigations dealing with water supplies. Reports of these investigations are on file at the offices of the Commission in Toronto. Ground-water surveys for the Town of Alliston (Sobanski, 1967), the Village of Beeton (Whitehead, 1969) and the Village of Tottenham (Yakutchik, 1961), have assisted in the development of municipal ground-water supplies. Pumping-test analyses of existing or new wells have been made for the villages of Cookstown, Shelburne and Tottenham. A continuing program of field and office work concerning the issuing of permits for water taking is being carried out by the OWRC Division of Water Resources.

Detailed studies of the overburden and bedrock geology have not been carried out specifically within the confines of the upper Nottawasaga River drainage basin, but a number of reports have been published about the geologic formations in the basin as part of broader investigations. Among the most notable publications describing bedrock geology in the area are the investigations made by Bolton (1957) on the Silurian stratigraphy of the Niagara Escarpment, by Sanford (1958, 1961, 1962) on the Ordovician and Silurian stratigraphy in southwestern Ontario, by Liberty (1953, 1966) on the geology of the Bruce Peninsula and Alliston area, by White *et al.* (1968) on the bedrock topography of the Bolton topographic sheet, by White (1968) on the Pleistocene geology of the Bolton area, and by Straw (1968) on the Pleistocene glacial erosion along the Niagara Escarpment. A more complete list of references on bedrock geology of the area is presented in "Selected Bibliography" at the end of this report.

The overburden deposits and physiography in the basin have been described in general by Chapman and Putnam (1966). A detailed discussion of Pleistocene geology in the vicinity of Lake Simcoe and in the adjacent Holland River watershed is presented by Deane (1950, 1966). Some of the geologic deposits adjacent to Lake Simcoe also occur in the Nottawasaga area and therefore some of his descriptions of Pleistocene geology are pertinent to this work. The discussions of Dreimanis (1953) concerning Pleistocene geology in the upper Holland River basin are similarly relevant. A complete description and classification of the soil types and land-use capabilities in the basin is presented by Hoffman *et al.* (1963, 1964). Included in these reports are soil-classification maps covering the counties of Dufferin and Simcoe.

A short economic survey of the counties of Dufferin and Simcoe is outlined by the Ontario Department of Economics and Development (1963).

Preliminary land-use maps prepared by the Geographical Branch of the Canada Department of Mines and Technical Surveys (1965) include the entire drainage basin.

Numerous water wells have been drilled for residents of the basin, and records for many of the wells have been submitted to the OWRC. These records, dating back to 1947, contain information about geologic formations, aquifer pumping tests, and other well particulars.

Acknowledgements

The survey was carried out under the general supervision of Mr. T. J. Yakutchik. Editorial assistance was provided by Mr. D. N. Jeffs, Mr. K. Goff and Mr. H. A. Flotner.

Field and office work contributions in water sampling, water-use survey, surfical geology mapping, and associated investigations were made by Messrs. G. Kendrick, D. Sharma, G. Gray, and F. Schwartz.

Co-operation was received from residents in the basin during the water-use survey and chemical-sampling programs. Thanks are due to two residents in particular, Mr. A. Copper and Mr. J. Marshall, who permitted the use of abandoned wells on their properties to be used as observation wells.

The Ontario Department of Lands and Forests and the township officials of Simcoe County gave permission to install piezometers in conservation areas and on road allowances.

GEOGRAPHY

Physiography

The upper Nottawasaga River basin has a highly contrasting physiography which in essence consists of a low, flat central plain rimmed by rolling hills and uplands. The basin may be divided into the following physiographic regions (Figure 2, in pocket):

1. Escarpment Upland Region
2. Kame Hills Region
3. Ground Moraine Region
4. Sand Plain Region

Escarpment Upland Region

This region occupies the most westerly portion of the basin west of and including the Niagara Escarpment. The Niagara Escarpment is a prominent physiographic feature locally and is exposed as cliffs, 125 to 150 feet high, for short distances north and south of Mono Centre. At other localities the escarpment is buried by glacial debris and is difficult to define. Although the general land-surface elevations range from approximately 1525 to 1700 feet, some of the river valleys along the escarpment are incised to levels of 1272 feet. Most of the land-surface elevation is approximately 1600 feet.

The land surface is characteristically gently rolling with subdued ridges separating poorly drained depressions which commonly contain swamps and bogs. Eroded into the rolling till plain are shallow outwash channels and subdued drainage courses that form the dendritic pattern of headwater drainage of the Nottawasaga River and its tributaries, the Boyne River and Sheldon Creek.

Most of the area is covered by loose, stony, ablation till on which occur scattered pond deposits of fine- to coarse-grained sand, and outwash deposits of sand and gravel.

Kame Hills Region

The Kame Hills physiographic region consists of an assortment of kame sands and gravels and other coarse-grained ice-contact and meltwater deposits. In the southern portion of this region the surface materials are mainly outwash sands and gravels deposited by glacial meltwater.

The region is bounded on the west by the Escarpment Upland and on the east by the Ground Moraine and Sand Plain regions. Generally, the land surface slopes towards the east, and elevations range from 800 feet in the river valleys to 1500 feet in the area of kame deposits adjacent to the escarpment.

The land surface is rugged (Plate 1), in places deeply dissected, and displays two levels of kame terrace (Map 2743B-4). A level, continuous terrace exists at an approximate elevation of 1400 feet and flanks the cliffs and, presumably, the buried portion of the escarpment. The other terrace occurs at an approximate elevation of 1000 feet and is located farther to the east.

Plate 1. Typically rugged terrain of the Kame Hills physiographic region just east of the Niagara Escarpment.

The drainage pattern in the region is mainly dendritic; however, many of the streams near the base of the escarpment are parallel to it and display a somewhat linear orientation. Because of the porous surface material of sand and gravel, drainage in most of the Kame Hills region is very good.

Ground Moraine Region

There are four Ground Moraine areas in the basin. The land-surface elevations range from about 725 feet near the Sand Plain region, to approximately 1375 feet southwest of Rosemont. Most commonly, however, the surface elevation is in the order of 800 to 900 feet. The area west of Alliston has the largest relief while the other three areas contain more gently rolling topography accentuated by northeast-southwest trending drumlins which characterize the Ground Moraine region.

The main surface deposit in the region is a sand to silt till, but local deposits of clay, sand, and gravel exist in the eastern and southeastern portions of the region. Drainage is poor to good in the till and generally good in the sand deposits. The surface drainage system, which is improved at some localities by ditches and open canals, is mainly dendritic and contains small streams that are intermittent during the summer months.

Sand Plain Region

The Sand Plain physiographic region consists of the flat-lying areas that occur adjacent to the Nottawasaga River for most of its length in the basin. Large portions of the drainage areas of the Boyne River and Sheldon and Innisfil creeks are also part of the Sand Plain region.

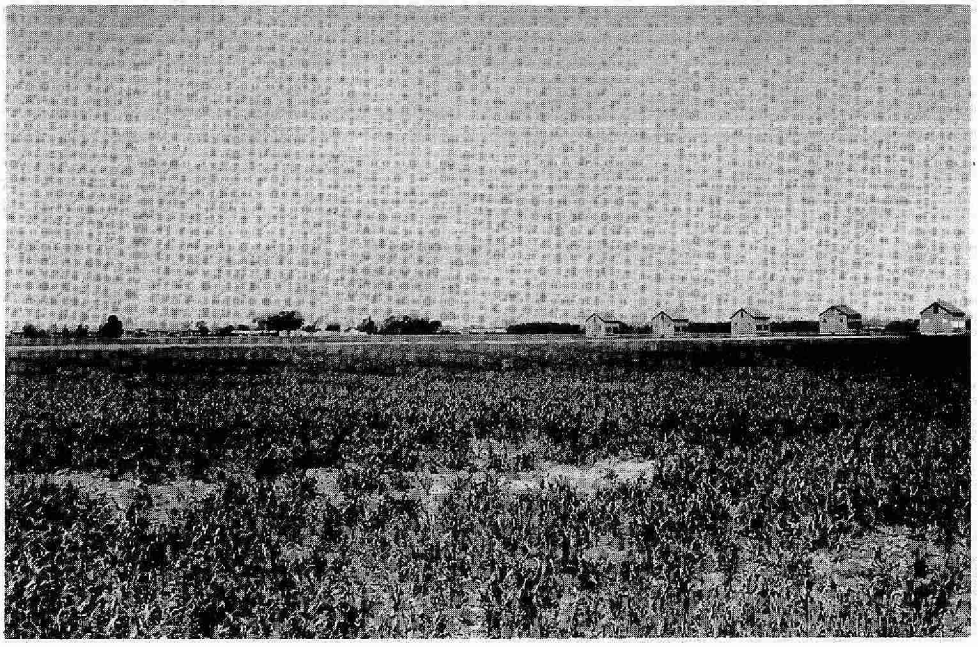


Plate 2. Typically flat terrain of the Sand Plain physiographic region southeast of Alliston.

The region is generally one of very low relief (Plate 2). Although the land-surface elevations, exclusive of the present level of the Nottawasaga River flood plain, range from about 700 to 1100 feet within the region, most of the surface elevations are below 750 feet. Maximum relief occurs in the upstream portion of Hockley Valley southwest of Hockley, and in the upstream portion of the Boyne River.

Surface drainage varies from poor to good and is mainly by infiltration of water into the ground rather than by overland flows to streams. Where low land-surface gradients are coupled with slow infiltration of precipitation, bogs and swamps exist, a condition prominent along Innisfil, Beeton, and Bailey creeks. Drainage channels have been constructed in some of these poorly drained areas, but their effectiveness is limited by low channel-bed gradients towards the main streams.

The flat topography of the Sand Plain is broken by partially sand-covered drumlins which are extensions of the drumlin topography located in the Ground Moraine areas.

Most of the surface deposits in the region consist of fine- to medium-grained sand deposited in glacial Lake Algonquin. At some lower elevations, very fine sand, silt, and thin clay deposits are present. Above the shoreline of Lake Algonquin, most of the surface deposits are sand and gravel of glacial meltwater origin.

Climate

A classification of climatic regions in Ontario is indicated by Ontario Department of Agriculture and Food (1966). Within this classification most of the upper Nottawasaga River basin is in the "Simcoe and Kawartha Lakes" climatic region and only a small portion of the western area of the basin is in the "Dundalk Upland" region.

During the summer of 1968, three permanent meteorologic stations and a precipitation gauge located at two different sites were in operation in the drainage basin. Meteorologic stations closest to the basin are situated at Orangeville, Albion, Bradford, Redickville, Camp Borden, Essa, and Barrie (Map 2743B-2). The meteorologic data at Beeton are assumed to indicate climate in the basin. The 30-year (1931-60) normal precipitation at this station is 30.83 inches; the highest annual precipitation of 45.40 inches occurred in 1964 and the lowest of 21.51 inches in 1946. The normal monthly precipitation values are shown in Figure 3, together with the maximum and minimum monthly values for the period of record.

The long-term average annual temperature is 44.6°F; the maximum temperature of 104°F (Figure 4) was recorded in July and the lowest temperature of −33°F in December.

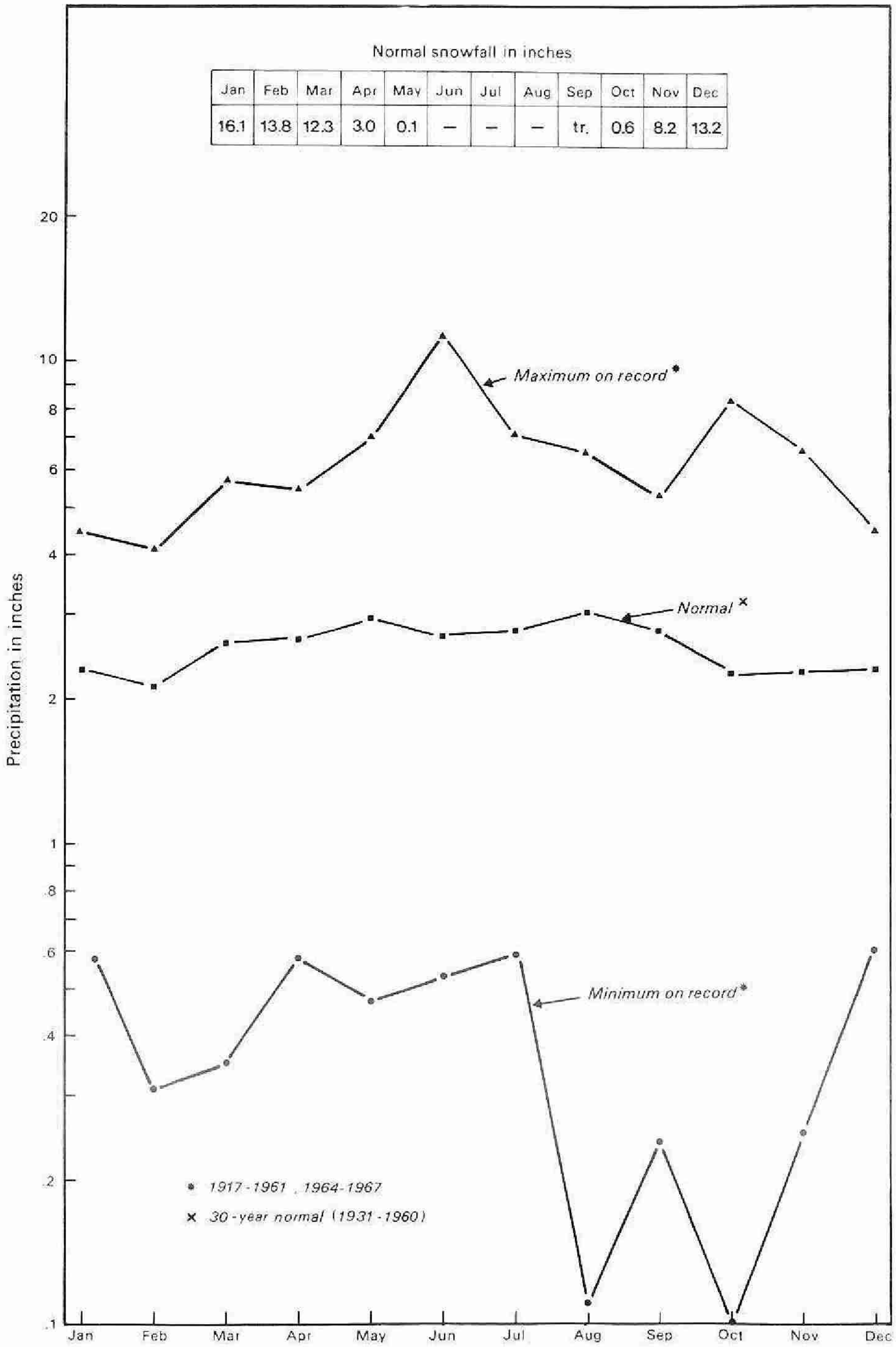
As no climatological stations within the basin report "frost-free" days and "growing-season" lengths, the values for Lindsay, which is also in the "Simcoe and Kawartha Lakes" climatological region, are considered useful as indicators of these parameters in the study area. The long-term frost-free season at Lindsay is 133 days—May 16 to September 26. No long-term average growing-season length is available.

Population and Economy of the Basin

Based on the 1968 assessment (Ontario Department of Municipal Affairs, 1969) the population of the basin in 1968 was estimated to be 22,000, of which about two-thirds was rural (Table 1).

Table 1. Population Distribution in the Upper Nottawasaga River Basin in 1968

AREA	POPULATION (1968)	
	Rural (estimated)	Urban (assessed)
DUFFERIN COUNTY		
Amaranth Twp.	300	
Melancthon Twp.	300	
Mono Twp.	2000	
Mulmur Twp.	500	
Village of Shelburne		1395
SIMCOE COUNTY		
Adjala Twp.	1700	
Essa Twp.	3200	
Innisfil Twp.	2100	
Tecumseth Twp.	2600	
Tosorontio Twp.	300	
W. Gwillimbury Twp.	1200	
Town of Alliston		3214
Village of Beeton		998
Village of Cookstown		715
Village of Tottenham		909
Pc. Village of Thornton		235
PEEL COUNTY		
Albion Twp.	negligible	
YORK COUNTY		
King Twp.	negligible	
TOTAL	14,200	7,466



Normal snowfall in inches

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16.1	13.8	12.3	3.0	0.1	—	—	—	tr.	0.6	8.2	13.2

Figure 3. Normal, maximum, and minimum monthly precipitation at Beeton, Ontario.

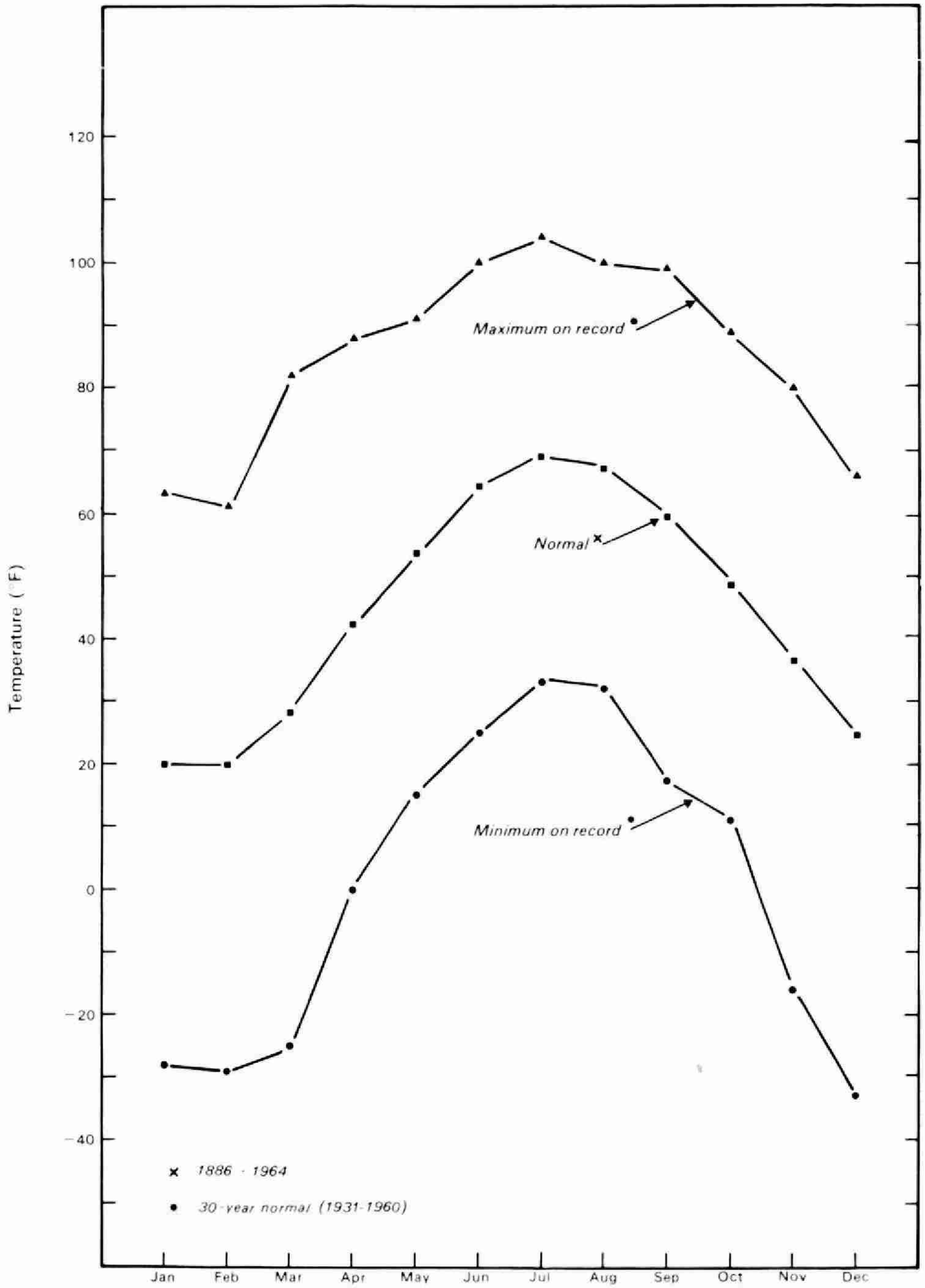


Figure 4. Normal, maximum, and minimum monthly temperatures at Beeton, Ontario.

Alliston has had the largest rate of population growth, especially since 1931, while Beeton and Shelburne have experienced lesser rates (Figure 5).

Populations in the townships of Amaranth, Melancthon, and Mulmur in Dufferin County have generally decreased from 1911 to 1968. Populations in townships in Simcoe County declined from 1911 to 1941 but have since shown a gradual increase.

The basin economy is primarily agricultural with emphasis on livestock-raising and mixed farming. A number of special cash crops are cultivated, the most notable being tobacco, potatoes, and sod. These crops are grown almost exclusively on the sand plain in the eastern half of the basin.

There are only a few large industries in the basin. Canada Packers Ltd. operates a poultry eviscerating plant at Shelburne. Honey, tire pumps, and lumber products are also produced in the village (Ontario Department of Economics and Development, 1963). The two main manufacturing concerns in Alliston are Salada Foods Ltd., which operates a potato processing plant, and Baxter Laboratories of Canada Ltd., which produces hospital supplies.

Land Use

Detailed maps of land use in the basin have been prepared by the Canada Department of Mines and Technical Surveys (see Figure 6, in pocket). A brief summary of land utilization is given in this report.

The primary uses of land in the basin are for cropland on the sand plain adjacent to the Nottawasaga River, and for improved and unimproved pasture throughout much of the remainder of the basin. Productive woodland areas are most common west of the escarpment and usually occupy river valleys or wet, marshy areas.

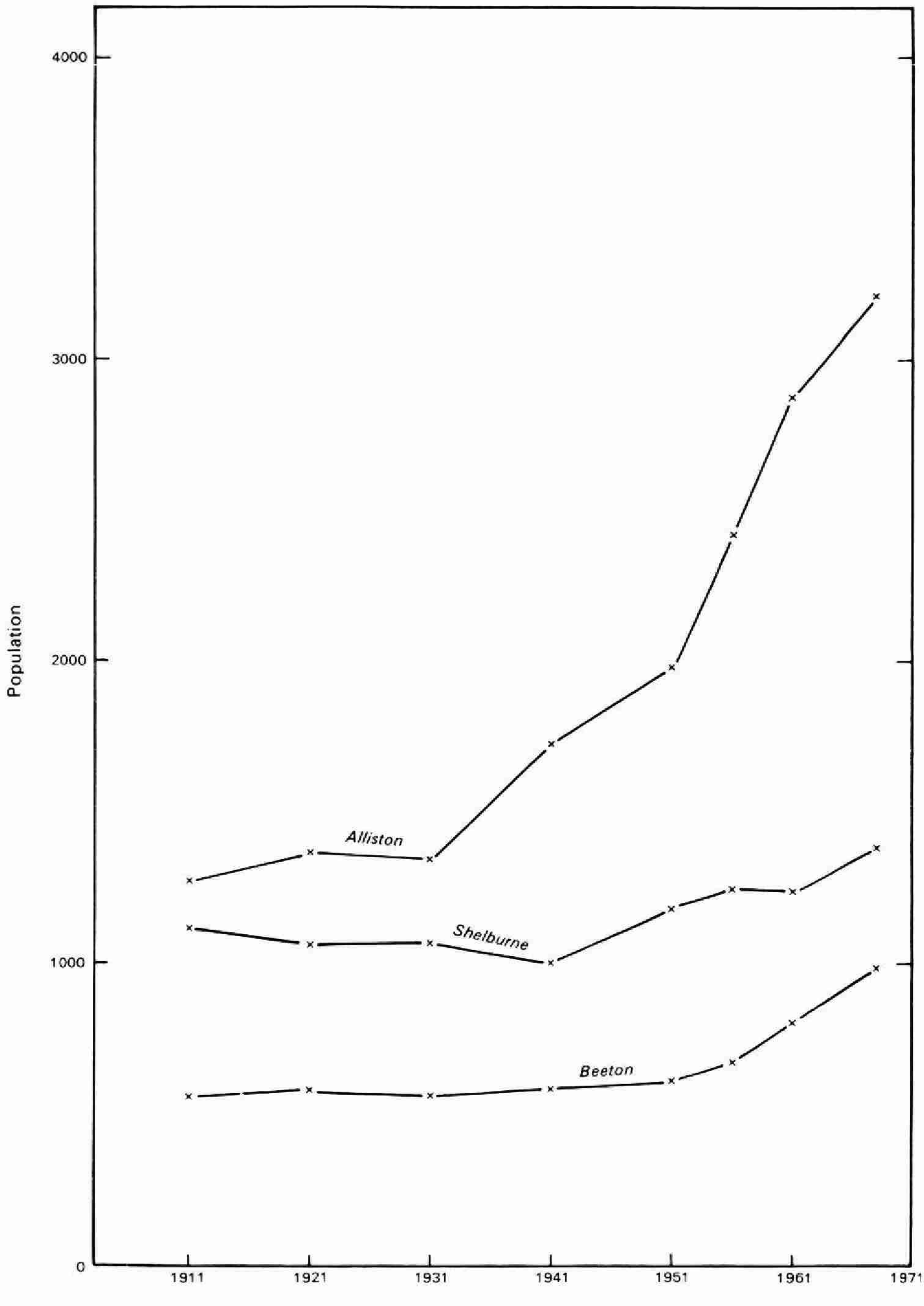


Figure 5. Population trends in the Town of Alliston and the villages of Beeton and Shelburne, for the period of 1911 to 1971.

GEOLOGY

Introduction

Geology is of prime importance in evaluating the occurrence, movement, and quality of surface and ground water in a watershed. The distribution of surficial deposits controls surface-water runoff and the infiltration of precipitation, and subsurface materials determine the occurrence and movement of ground water. As each material and deposit can be associated with a certain range of permeabilities, the mapping of surface and subsurface deposits serves to indicate the distribution of permeable and semi-permeable geologic formations.

Surficial deposits were mapped in detail in the upper Nottawasaga River basin. Discussions of the occurrence of these deposits are aimed at differentiating the permeable from the semi-permeable deposits and at indicating the probable yield of ground water to be expected from each formation.

Overburden in the upper Nottawasaga River basin is the result of sediment deposition, erosion, and modification that occurred during glacial and interglacial periods in the Pleistocene Epoch. The thickness of these unconsolidated deposits in the basin varies from 0 to 500 feet, but the stratigraphy of only the uppermost part is known in detail.

The overburden consists of glacio-lacustrine (lake) sediments, fluvial (river) and glacio-fluvial deposits, and ice-deposited drift. The glacio-lacustrine sediments of medium- to fine-grained sand, silt, and clay were deposited in ice-marginal lakes and ponds associated with glacial Lake Schomberg and subsequent phases of Lake Algonquin. The materials in fluvial and glacio-fluvial outwash deposits vary from well-bedded and sorted sand and gravel in outwash plains and meltwater channels, to irregularly stratified sand and gravel in kame hummocks.

Ice-deposited drift, commonly referred to as "till", consists of unsorted and unstratified sediment deposited directly by a glacier. The composition of till in the basin varies from a very loose, rubble-like "ablation till", to a compact, consolidated sand, silt, or clay "lodgement" till. Land forms of till in the basin include drumlins, till plains, and end moraines.

Except for the relatively permeable sand till in the eastern portion of the basin, tills are semi-permeable and do not readily transmit water. Lacustrine silt and clay sediments are also semi-permeable, while fluvial sands and gravels, and coarse-grained lacustrine sand deposits are permeable and can transmit large quantities of ground water.

Bedrock underlying the drainage basin consists of shale, dolomite, and limestone deposited in seas that covered the area during the Ordovician and Silurian periods of the Palaeozoic Era. Wells constructed in limestone and dolomite on top of the escarpment yield sufficient quantities of water for domestic use; however, wells which penetrate shale and limestone east of the escarpment, if not dry, usually yield marginal supplies for domestic purposes.

Bedrock Geology

Stratigraphy

The Palaeozoic stratigraphy of southern Ontario has been studied by numerous investigators. The results have been published, among others, by Bolton (1953), Liberty *et al.* (1968),

Table 2. Bedrock Stratigraphy in the Upper Nottawasaga River Basin

System	Rock Units			Description
	Group	Formation	Member	
Silurian	Albemarle	Amabel	Eramosa	Dolomite; thin bedded, dark brown, fine-grained and highly bituminous
			Wiarton	Dolomite; massive, coarse- to fine-grained, crinoidal
			Colpoy Bay	Dolomite; massive, porous, fine-grained to dense, white to light grey; unfossiliferous except for local bioherm masses
		Fossil Hill		Dolomite; fossiliferous, irregularly bedded, dark grey weathering
	Cataract	Cabot Head		Shale; soft, red and green with thin limestone and gypsum beds
		Manitoulin		Dolomite to dolomitic limestone; grey weathering, brown, fine and medium crystalline with grey shale partings
		Whirlpool		Sandstone; massive, white to light grey, fine-grained, unfossiliferous
Ordovician		Queenston		Shale; red, with occasional green shale interbeds and grey crystalline and silty limestone
		Meaford-Dundas, Blue Mtn.		Shale and limestone; grey, calcareous siltstone, grey, silty limestone, with interbedded grey shale. Blue Mountain consists of soft, grey and bluish grey shale
		Collingwood		Shale; dark brownish grey to black, fissile, bituminous
	Trenton	Cobourg		Limestone; dark brown, dense, argillaceous, very fine-grained
		Sherman Falls		Limestone and shale partings; grey, finely crystalline to fragmental, with shale partings and interbedded dark grey shale
		Kirkfield		Limestone; greyish brown to dark grey, finely crystalline, fragmental, carbonaceous and shaly

Note: This table has been compiled on the basis of Bolton 1957, Liberty 1969, and Sanford 1969.

and Sanford (1958, 1961, 1962, 1969). These reports form the basic references for the description of bedrock stratigraphy in the upper Nottawasaga River basin. The bedrock formations underlying the basin are shown on Map 2743B-3 and described in Table 2.

The Silurian rocks range downward from dolomites of the Amabel Formation through shale and limestone of the Cabot Head Formation to the Whirlpool sandstone. The Amabel dolomites are the best water-yielding rocks in the basin. The permeable Whirlpool sandstone, the oldest Silurian bedrock in the watershed, disconformably overlies poorly permeable Ordovician shales.

The Ordovician rocks range downward from the red shales of the Queenston Formation to limestones of the Trenton Group. These rocks, in their unweathered state, rarely yield large quantities of water to wells. Often the extractable quantities of water from these rocks are negligible.

Topography

The purpose of investigating bedrock topography in the basin is twofold: 1) to identify bedrock valleys or channels that may serve as potential aquifer sites if filled with coarse sand and/or gravel, and 2) to define bedrock highs, escarpments, and depressions that may influence ground-water occurrence and movement, and surface-water drainage patterns. The topography of the bedrock surface is illustrated on Map 2743B-3.

The Niagara Escarpment is a prominent topographic feature on the present land surface as well as on the buried bedrock surface. Incised into the escarpment is a deep bedrock valley, the trend of which approximates the overlying Hockley Valley. Three other significant bedrock channels occur along the escarpment (Figure 7). All are thought to have been formed by fluvial or glacio-fluvial erosion. The largest, of which only a remnant remains, is inferred to have extended between the escarpment and the bedrock highs beneath Violet Hill and Sheldon Hill at elevations between 1100 and 1200 feet.

The second channel is located near the northern end of the escarpment outcrop where the valley floor is at an approximate elevation of 1200 feet.

The third channel is located between the exposed face of the escarpment and the three small bedrock promontories immediately east of the escarpment. The approximate elevation of the floor of this channel is 1400 feet, and the channel was probably formed by meltwater erosion during a stage of deglaciation of the escarpment.

Bedrock topography is generally reflected by the land-surface configuration in the basin. For example, Violet Hill, Sheldon Hill, and Mono Hill are all underlain by bedrock highs, as is the Singhampton moraine on the crest of the escarpment. Hence, where bedrock control is poor, surface topography may be used as a guide in extrapolating the shape of the bedrock surface.

Surficial Geology

The overburden deposits in the basin are related mainly to glaciation of the area during the Pleistocene Epoch. During this epoch, four main glacial ages occurred, each separated by an interglacial (warm) stage. The effects of only the most recent (Wisconsinan) glaciation are displayed by the surface deposits and land forms in the area (Map 2743B-4). This last ice sheet either removed deposits left by earlier glaciers or completely buried them.

Some deposits were laid down either directly under the ice or adjacent to the ice margin, while other materials were deposited in proglacial meltwater stream channels, outwash plains, or in pondings and glacial lakes fed by meltwaters from the glacier. Till deposited directly beneath the ice forms "ground moraine". Till pushed up at the end of a glacier, or deposited at a stationary ice front, may occur in the form of high, elongated ridges called "end moraines".

In contrast to till deposits and associated land-forms, glacio-fluvial deposits consist of

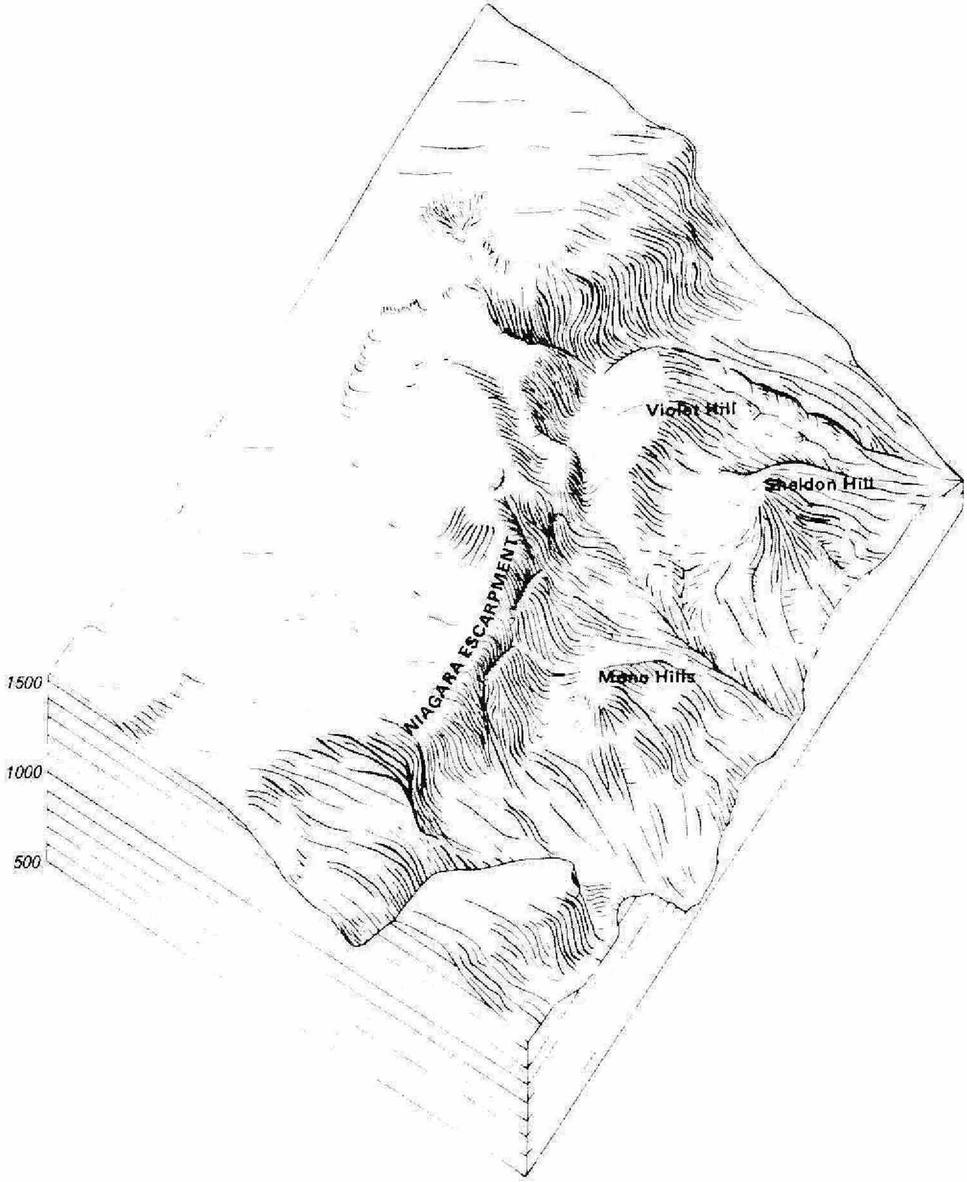


Figure 7. Location and extent of three bedrock channels in the vicinity of the Niagara Escarpment in the Upper Nottawasaga River basin.

sorted and stratified silt, sand, and gravel in land forms distinctive of their mode of deposition. Individual "kames" may form isolated hills of sand and gravel; an assemblage of kame deposits forms a hummocky landscape of high relief (Plate 3). A "kame terrace" of stratified sand and gravel is typically flat on the surface and is formed by deposition by meltwater flowing between the melting ice front and an adjacent valley wall. Sand and gravel deposited by meltwater in a broad, flat, fan-like form is known as an "outwash plain". Lacustrine (lake) deposits of clay, silt, and sand form typically flat plains below the elevation of the shorelines of the lake.

The most permeable overburden deposits are the coarse-grained sands and gravels of glacio-fluvial, fluvial, and lacustrine origin. It is these deposits in particular that form important aquifers within the overburden.

Fine-Grained Lacustrine and Pond Deposits

Fine-grained deposits of clay, silt, and fine sand were deposited in glacial Lake Algonquin and Lake Schomberg (Plate 4 and Plate 5), as well as in small isolated ice-marginal pondings near some of the drumlins in the eastern and northeastern parts of the watershed. Except for the Lake Algonquin silts located between Cookstown and Beeton, these deposits are not extensive on the surface. However, thick sequences of clay and silt directly underlie till in portions of the till plain areas of the basin. The silt and clay deposits are often associated with coarse-grained sands that occur at elevations above 900 feet; the origin of these sands is uncertain and their subsurface extent is unpredictable.

Because of their fine grain size, limited thickness, and erratic subsurface occurrence, the fine-grained lacustrine and pond deposits are a poor source of ground water. Only a few wells, located on the Innisfil Creek plain southwest of Cookstown, derive water from these deposits.

Plate 3. Hummocky kame topography on the north side of the Nottawasaga River; looking southwest towards the river; Mono Twp., Con. III EHS, Lot 2.

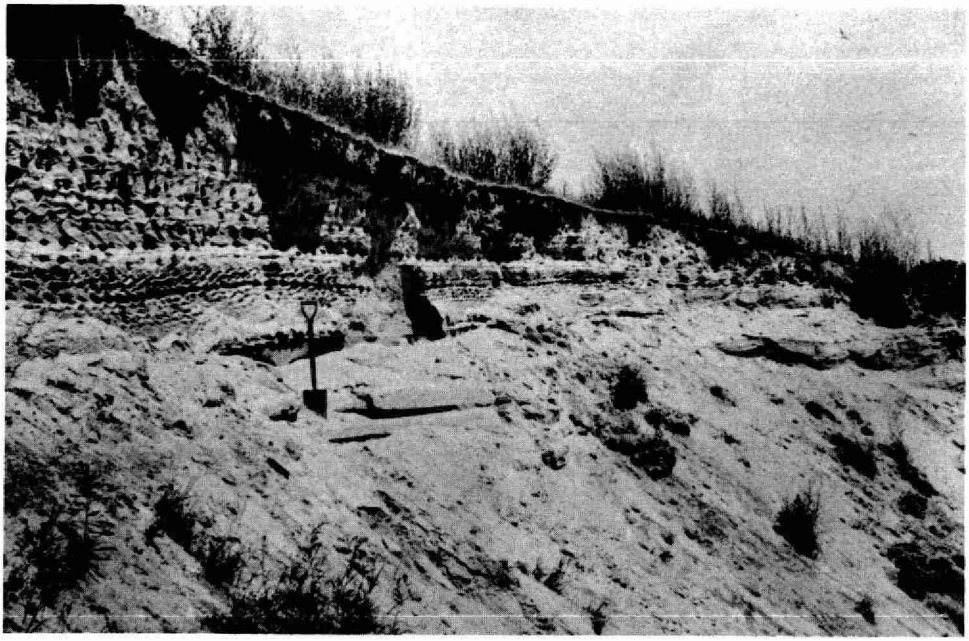


Plate 4. Ripple marked Lake Schomberg sand overlain by sand till (see Plate 5); looking north; W. Gwillimbury Twp., Con. XV, Lot 12.

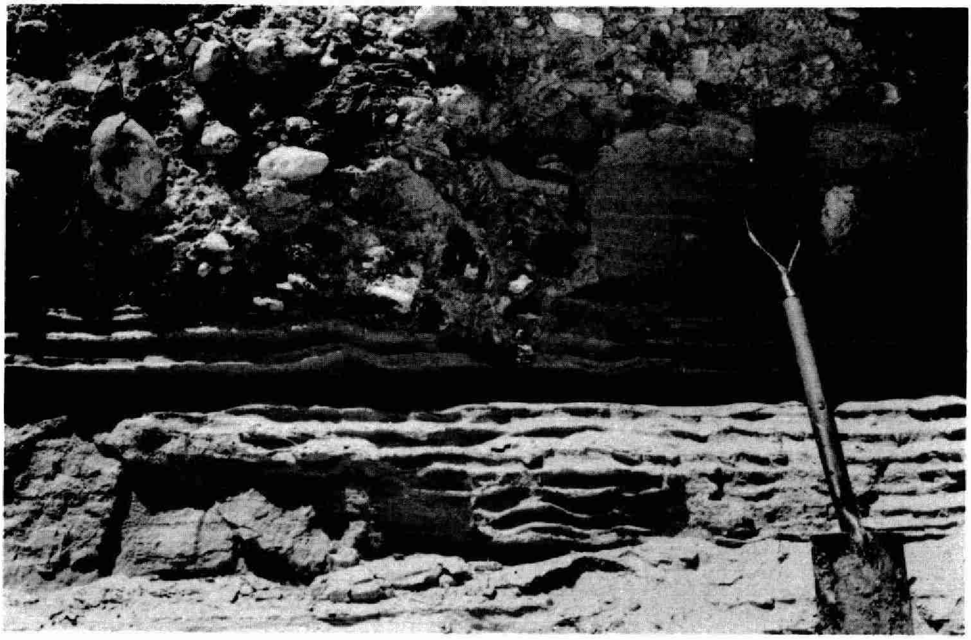


Plate 5. Detailed portion of Plate 4 showing the invasion of stony sand till into underlying Lake Schomberg sand deposit.

Coarse-Grained Lacustrine and Pond Deposits

Surface deposits of medium- to coarse-grained sands, and occasionally gravel, are located on the flat plain near Innisfil Creek and the lower part of the Nottawasaga River. As much as 50 feet of sand, interbedded with minor beds of silt and clay, can be noted in the banks of the Nottawasaga River. These sand deposits thin towards the 750-foot surface contour and disappear along the main Lake Algonquin shoreline. Subsurface occurrences of coarse-grained sands and gravels are associated either with glacial till deposits, in which case they are of limited thickness and extent, or with early lakes that inundated large portions of the basin east of the Niagara Escarpment. The locations of extensive buried lacustrine sand and gravel deposits are shown on Map 2743B-5 and are described in the section on ground-water occurrence.

Lacustrine sand deposits, whether surficial or buried, are favourable aquifers, and wells constructed in these sands will yield sufficient water for domestic uses.

The coefficients of permeability determined for three samples of surface sands vary from 4×10^{-2} to 7×10^{-2} inches per minute (in./min.) (Table 4).

Proglacial Outwash Deposits

Proglacial outwash deposits consist of stratified sands and gravels deposited by meltwater streams beyond the terminus of the glacier. In the upper Nottawasaga Riven basin, prominent proglacial outwash deposits occur as three distinct land forms:

(1) a remnant, flat, outwash fan above an elevation of 1000 feet north of Thornton;

(2) a rugged area of sands and gravels near the southern boundary of the basin southeast of Hockley;

(3) relatively narrow outwash-filled channels in the vicinity of the Niagara Escarpment and to the west.

The origin of the thin surficial sand and gravel deposit near Thornton is not known; however, its considerable extent suggests a large area of meltwater deposition at an elevation close to 1000 feet. Outwash southeast of Hockley is part of the large interlobate ice-contact material that was deposited after the ice sheet split into the northern and southern lobes. The sands and gravels in the outwash channels near the escarpment are about five to ten feet thick and were deposited by meltwater from local ice fronts.

Outwash deposits are usually very permeable and, where thick enough, are reliable sources of ground water. The occurrence and extent of subsurface deposits of outwash are discussed in the section on ground-water occurrence.

Kame Terrace Deposits

The kame terrace deposits consist of well-bedded sands and gravels, usually about 20 to 30 feet thick, and are located on the flat terraces just east of the Niagara Escarpment.

Two major levels of kame terrace exist in the basin. One is located at the foot of the escarpment at an elevation of about 1400 feet. It was formed by meltwater contained between the escarpment and the ice, and flowed southward through the spillway near Orangeville. Within a series of other (younger) terraces found at elevations between 975 and 1075 feet, a very prominent one occurs at an elevation of about 1000 feet (Plate 6). The 975-foot terrace north of Hockley is scarred by closed depressions known as "kettles". The outlet for the meltwater that formed this terrace is not evident, but it may have been across the southern drainage boundary just west of Mount Wolfe. The material in the lower terraces, generally finer than the deposit at the 1400-foot level, is mainly sand near the surface with minor amounts of gravel at depth (Plate 7).

Where saturated, the sands and gravels in these deposits form excellent aquifers that are capable of transmitting large quantities of water. Adequate farm and domestic supplies are

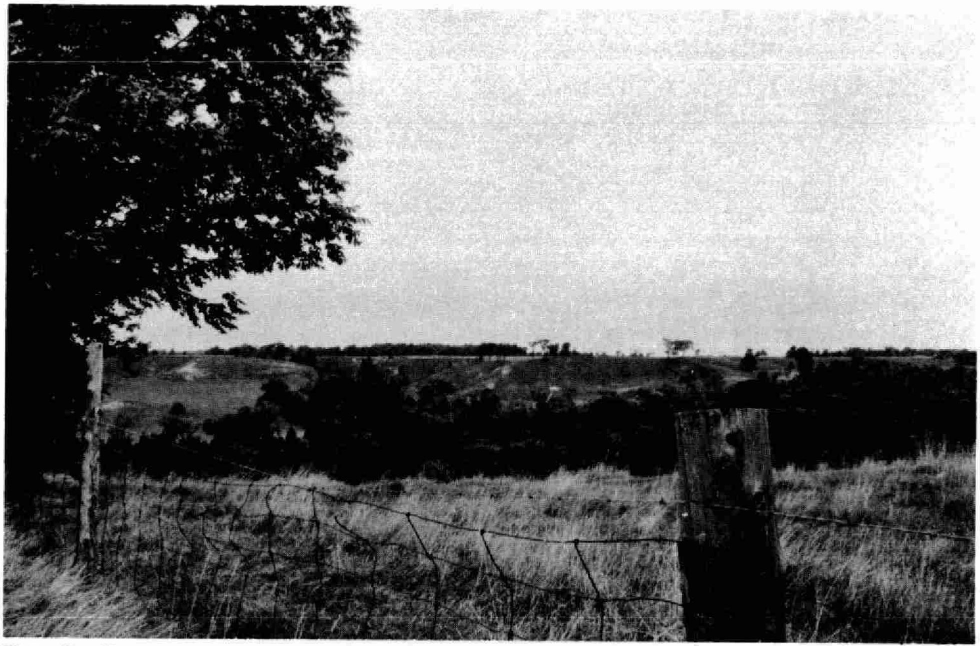


Plate 6. Kame outwash terrace (in the background) at the 1000-foot elevation displays typically flat surface topography; looking northeast; Mulmur Twp., Con. VIII, Lot 8.

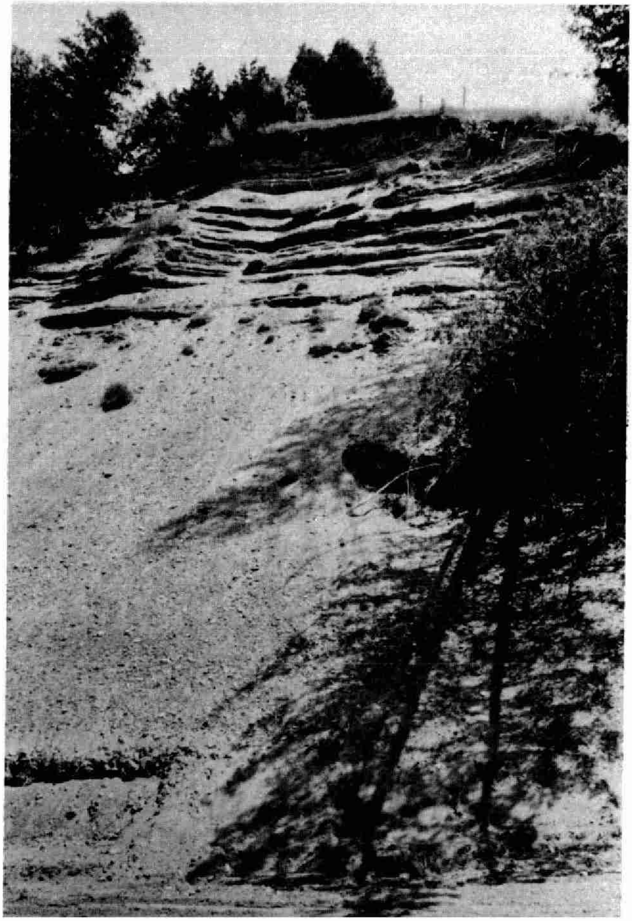


Plate 7. Approximately 60 feet of outwash sand and gravel associated with the 1000-foot kame terrace just south of Hockley; looking east; Adjala Twp., Con. I, Lot 12.

usually obtained from shallow dug wells. A number of wells, however, especially on the 1400-foot terrace, have been unsuccessful because of thin, saturated thicknesses.

Kame, Ice-Contact Deposits

Ice-contact deposits in the form of kames, kame terraces, and eskers are deposited in direct contact with wasting ice. As the material is deposited by meltwater flowing from the top of or within the ice, the deposits of silt, sand, and gravel are usually irregularly bedded and variably sorted. This material will often grade into finer-grained sediments of pro-glacial outwash located farther downstream.

The most extensive kame deposits in the basin are located just east of the escarpment. Small amounts of kame sand and gravel are found in a few localities on top (west) of the escarpment. Kame deposits also occur directly beneath the sand till. An example of such an occurrence is the gravel pit two and one-half miles due south of Beeton (Plate 8) where the kame is capped by about five feet of sand till. The deposit consists of steep, southwesterly dipping sand and gravel beds which indicate an ice front to the northeast.

Kame deposits of sand and gravel form good water-bearing formations, and their usefulness as sources of water supply is dependent mainly on sufficient thicknesses of saturated material. In most cases, the water-table is relatively deep in the surficial kame deposits and consequently, deep wells must be constructed. Confined ice-contact deposits, as found underneath the till in the eastern portions of the basin, are consistently reliable water-bearing formations which yield sufficient quantities of good quality water for domestic use.

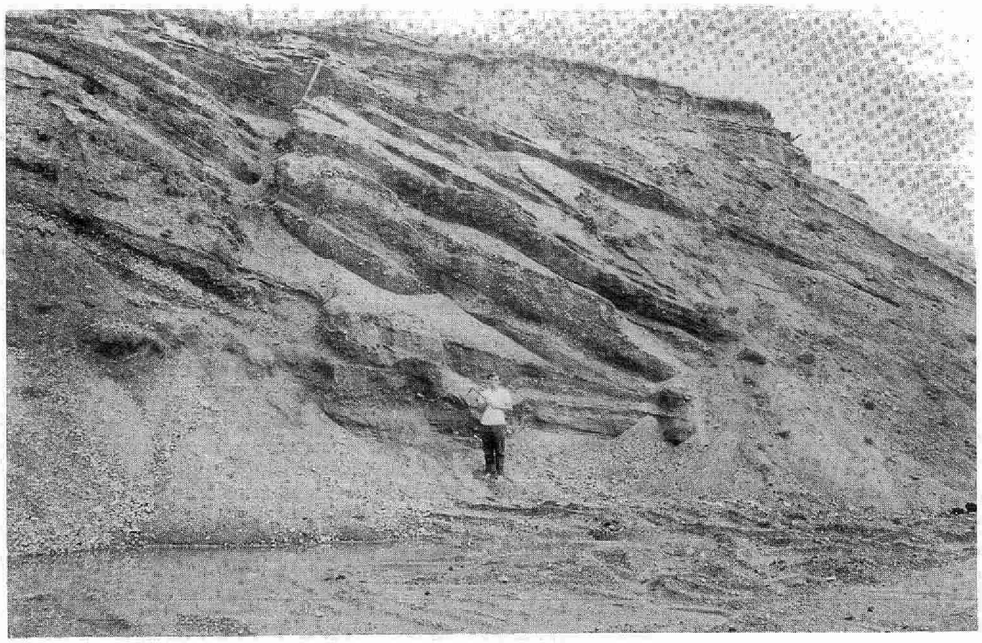


Plate 8. Ice-contact stratified drift of steeply dipping sand and gravel; looking southwest; Tecumseth Twp., Con. IV, Lot 10.

Morainic Deposits

The composition of ground moraine in the watershed ranges from a basal, silty sand till in the eastern section of the basin to a clayey silt till in the mid-portions of the till plain areas. All till in the ground moraine east of the escarpment was deposited during the last retreat of the Georgian Bay — Lake Simcoe ice lobe.

The bulk of the ground-moraine deposits west of the escarpment are composed of semi-consolidated, stony, sandy silt till which is distinctly different in texture and structure from the tills below the escarpment. At some locations along the escarpment the surficial till is a rubble of black and red shale in a red clay matrix. The till plain on top of the escarpment is gently rolling; the ground moraine east of the escarpment portrays rugged topography accentuated by many drumlins.

For the purpose of till correlation and classification, 24 till samples were collected for mechanical analysis. Seven samples were obtained at depth during drilling, and 17 were collected from surface sources (see Map 2743B-4 for sample locations).

The majority of till samples are similar in composition (Table 3 and Figure 8) to the sand till described by Deane (1950) in the Lake Simcoe area. One noteworthy till type is the sand till (Deane's Type 8) represented by sample 6, which is composed almost entirely of sand. Such tills are often very difficult to identify in the field as till; indeed, such a deposit in an adjoining basin has been referred to as"... loose, very sandy tills, or as sand and stones" (Deane, 1950, p. 22). Till samples 6, 7, 8, and 9, which were obtained from locations west of the escarpment, generally contained a larger percentage of gravel and stones than other samples in the basin. This stoniness is a distinguishing characteristic of the tills west of the escarpment.

Table 3. Mechanical Analyses of Tills from the Upper Nottawasaga River Basin

Sample No.	Sample Description	Depth below surface (feet)	Percentage			
			Gravel	Sand	Silt	Clay
1	Compact, brown, sand till	20	3	48	37	12
2	Compact, grey, silt till	25	2	21	52	25
3	Compact, brown, sand till	surface	9	53	28	10
4	Compact, brown, sand till	5	4	54	27	15
5	Compact, grey, stony, silt till	surface	8	37	42	13
6	Loose, brown, very sandy till	surface	9	72	13	6
7	Compact, brown to red, very stony silt till	5	15	30	40	15
8	Compact, reddish brown, stony silt till	surface	21	5	64	10
9	Compact, brown, stony silt till	surface	12	31	45	12
10	Semi-compact, brown, stony, sand till	7	8	57	28	7
11	Compact, dark grey, silt till	5	0	8	74	18
12	Compact, brown, sand till	surface	4	43	39	14
13	Compact, brown, silt till	10	2	36	44	18
14	Compact, brown, sand till	surface	8	57	29	6
15	Compact, brown, sand till	15	2	52	36	10
16	Compact, brown, sand till	5	3	58	29	10
17	Compact, brown, sand till	surface	2	56	32	10

Note:The range of particle size for gravel, sand, silt, and clay is after the Wentworth classification as in Pettijohn (1944).

Most tills in the basin are poorly permeable and form semi-confining layers where they overlie more permeable water-bearing deposits. They generally yield small amounts of water to wells. However, some facies of sand till, as in the southern part of Tecumseth Township, are composed of fairly uniform-grained sand with very little fine-grained material. At such locations ground-water yield from the sand till is limited only by insufficient saturated thicknesses. Where this till is sufficiently thick, large-diameter wells can provide adequate quantities of fresh water for domestic uses.

The coefficients of permeability determined for three samples of the silt till vary from 2×10^{-3} in/min to 4×10^{-3} in/min. Permeabilities determined for two samples of clay till from depths of 52 and 71 feet were 10^{-5} in/min and 6×10^{-6} in/min. (Table 4).

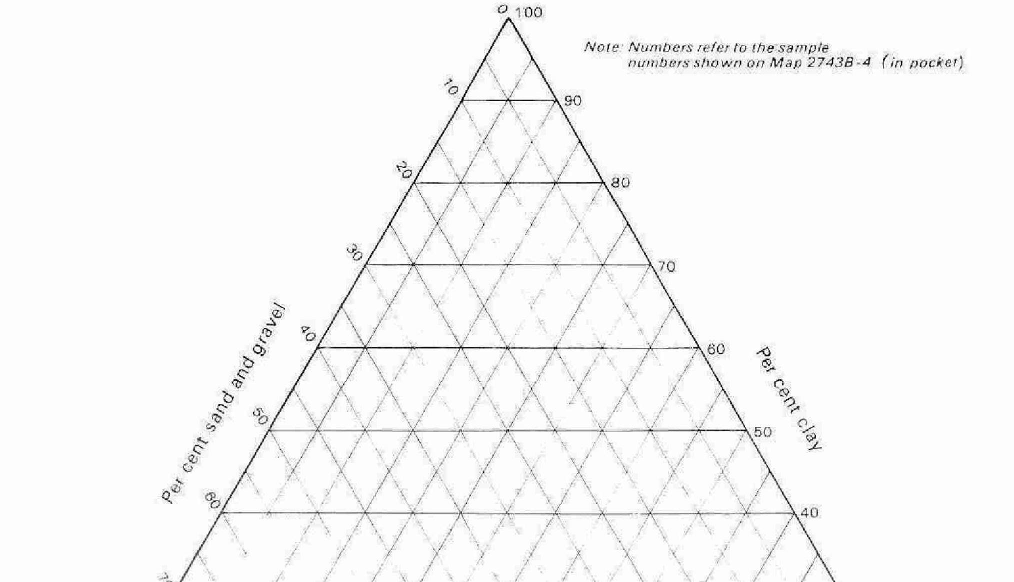


Figure 8. Trilinear chart showing the results of mechanical analyses of till samples in the Upper Nottawasaga River basin.

Drumlin Deposits

The drumlins in the basin are elongated hills with crests towards the northeast and the "tail" ends pointing southwest. Drumlins in the watershed occur exclusively east of the escarpment; most are located in the ground-moraine areas of the basin, and a few protrude through the surface sand deposit east of Alliston.

The cores of the drumlins are composed of silt to sand till. Deane (1950) states that "All large drumlins ... are composed, in part, of stratified material in the form of capping over the boulder-clay till .... In general, all drumlins that rise above an altitude of about 850 feet contain stratified sand and gravel on the top, ends or sides. The stratified material is always found near the crests, always on the southeastern slope, and in some cases, at one or both ends".

Sand and gravel deposits are associated with the drumlins, but the bulk of the drumlin material is semi-permeable silt till which is a poor water-yielding material. Because the drumlins are isolated high hills, the water-table at these sites may be deep and dug wells are often more than 30 feet deep.

Bar Deposits

Low, elongated ridges of stratified sand and gravel, formed in shallow-water lacustrine and fluvial environments, occur at an elevation of about 770 feet on the outwash plain southwest of Alliston, and at an approximate elevation of 730 feet on the Lake Algonquin sand plain due south of Alliston. The bars on the outwash plain are predominantly gravel, whereas those on the Lake Algonquin plain consist of sand with minor gravel lenses.

The bar deposits are not a significant source of ground water and have hydraulic characteristics similar to the materials on which they are located.

Alluvial and Swamp Deposits

Alluvial deposits consist of clay, silt, and fine sand, and are confined to recent stream terraces, normally where streambed gradients are low. Some recent flood plains, although topographically distinct, contain only small amounts of alluvium.

Swamp deposits consist of two to three feet of black organic material underlain by very fine sand, silt, and sometimes clay. The most extensive deposits are located in low areas on the Lake Algonquin sand plain adjacent to Innisfil and Bailey creeks.

Swamp and alluvial deposits are not good sources of ground water.

HYDROLOGY

Introduction

Hydrology deals with the properties, distribution, and circulation of water in the atmosphere, hydrosphere, and lithosphere. The movement of water in the total earth system is referred to as the "hydrologic cycle". On land areas the main processes within the cycle are: precipitation, surface-water runoff, subsurface flow, evaporation, and transpiration. Each process is active during the circulation of water from the land, sea and other bodies of water, through the atmosphere, and back to the land.

Within this cycle, however, only the water on or below ground surface can be used by man, and as in the utilization of other natural resources, this water needs to be managed for optimum development. To manage the use of water, an evaluation of the resource is essential. This evaluation, in terms of quantity and quality, is the primary purpose of this and the following sections of the report.

Ground Water

Introduction

Ground-water recharge occurs essentially through precipitation on land areas. During periods of low rainfall, ground-water levels will decline and wells that supplied adequate amounts of water during years of normal precipitation may become dry. During wet years, even shallow wells may yield adequate quantities of water. To avoid the risk of wells going dry or supplies becoming marginal, wells should be properly constructed in a deep or thick aquifer that will yield reliable amounts of water at all times.

The movement of water through subsurface formations is continuous and begins when precipitation infiltrates into the ground. Once the soil moisture deficiency is satisfied, the remaining portion of the infiltrated water will drain under gravity toward the zone of saturation (Figure 9). In this zone, water is in continuous movement towards areas of ground-water discharge. Such discharge may occur as evapotranspiration, seeps and springs, or water withdrawal through wells and ponds. Withdrawal through wells is not part of the natural ground-water discharge phenomenon and can occur in any part of the ground-water flow system. The ground-water phase of the hydrologic cycle is completed when ground water is discharged from the zone of saturation.

The rate of ground-water movement through subsurface formations depends on the permeability of the formation and the hydraulic gradient. The patterns of ground-water movement are determined by the continuity, extent, and permeability of the transmitting material, and by the hydraulic gradients between ground-water recharge and discharge areas. A ground-water recharge area is defined as an area where the direction of ground-water flow in the saturated zone is away from the water-table; a discharge area is defined as an area where the direction of ground-water movement is towards the water-table.

The knowledge of whether recharge or discharge conditions exist at a potential well site is important in well drilling and construction. For example, wells drilled in a recharge area will have increasingly lower static water levels with increasing depth, and conversely,

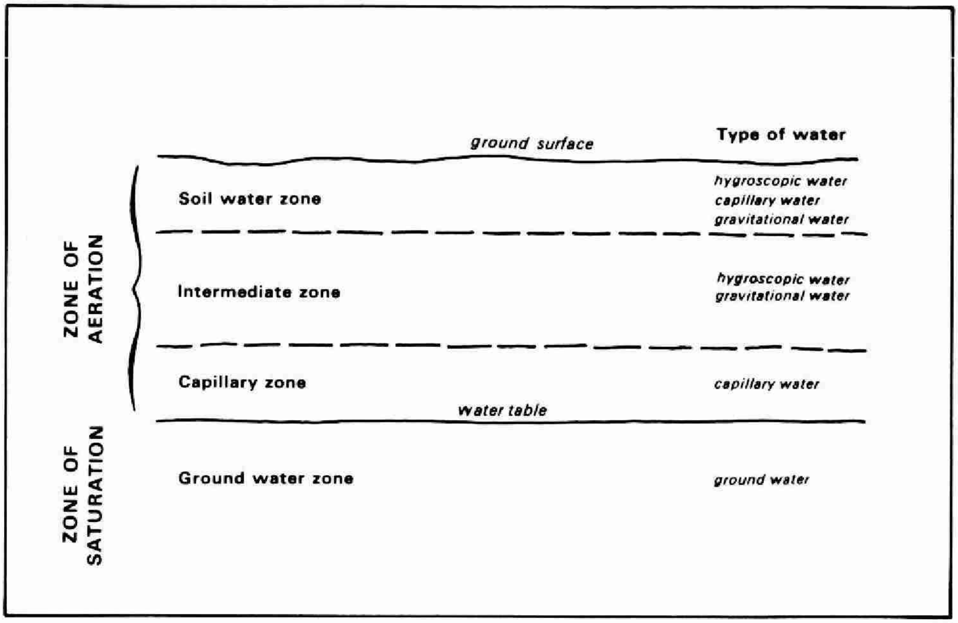


Figure 9. Division of subsurface water.

wells drilled in discharge areas will have increasingly higher static water levels with increasing depth. A depth may be reached in a discharge area where the static level of water is above ground surface, and the well will flow.

General Occurrence and Movement

Before specific occurrences of ground water are illustrated and discussed, a presentation of general ground-water conditions throughout the basin is given with reference to four hydrogeologic cross-sections (Figure 10, in pocket).

Section A-A'

The north-south section along Highway 27 indicates the general environment of ground-water occurrence in the eastern portion of the watershed. The deep permeable sands in the northern sections of the basin are part of the "Thornton sand aquifer" and are discussed under this heading.

Throughout most of the cross-section, water levels decline with increasing depth, suggesting conditions of ground-water recharge. An upward component of flow from the bedrock is shown in the area underlying the Innisfil Creek plain. However, it is doubtful that this condition exists at shallower depths, especially in the surface sands in which the flow is believed to be mainly lateral.

Section B-B′

This section shows flowing wells not only on the low Innisfil Creek sand plain, where the surface elevation is in the order of 720 feet, but also at land-surface elevations as high as 900 feet between Tottenham and the southern boundary of the drainage basin. It is believed that flowing wells on the sand plain are constructed in an extensive discharge area. The upward movement of water from the bedrock or from deep overburden aquifers is indicated by flowing bedrock wells at Beeton and on the sand plain to the north.

Section C-C′

This section, located along Highway 10 west of the escarpment, is characteristic of ground-water occurrence and flow conditions on top of the escarpment.

In contrast to ground-water flow east of the escarpment, many of the flow patterns in the overburden on top of the escarpment are localized by the undulating bedrock surface which is usually within 50 feet of the land surface. All the wells in the section obtain their water from permeable zones in the dolomite and limestone bedrock.

An area of ground-water discharge is indicated by flowing bedrock wells between Elba and Camilla, but the discharge is probably local because the vertical components of flow throughout the rest of the section are downward. As very few of the wells on the escarpment have penetrated deeply into the bedrock, the direction of flow in deep formations is unknown.

Section D-D′

The east-west section is located along Highway 89 and illustrates general hydrogeology throughout the length of the basin.

In addition to flowing wells noted in the Innisfil Creek and Nottawasaga River plains regions, two other areas of flowing wells are shown in this section: one occurs near Cookstown where a well flows from a depth of approximately 200 feet in the overburden, and the other is near Shelburne where two wells flow from a depth of 100 feet and are drilled into bedrock. The flowing wells near Shelburne very likely indicate a local discharge area, whereas flow at the well near Cookstown is the result of a regional discharge system.

Water levels measured in the upper 40 feet in the sands on the Innisfil Creek and the Nottawasaga River plains indicate that there is virtually no vertical hydraulic gradient in the sand (Table 5). The downward gradients in the rest of the basin are largest on the high till plain areas east of Alliston. West of Alliston, the thin overburden and irregular bedrock topography restrict flow systems in the overburden to local scales.

Ground-Water Occurrence in Bedrock

The occurrence and distribution of ground water in bedrock formations are governed by the rock type, structure, and in some cases, by the thickness and type of drift overlying the bedrock. Rock formations west of the escarpment contain the best bedrock aquifers in the basin and the use of water from them is widespread. Dolomite of the Amabel Formation is the most consistently productive bedrock in this area. The estimated thickness of the Fossil Hill Formation is only about eight feet, and it is thus considered to be an insignificant water-bearing formation. Productivity of the dolomites in the Cataract Group is not known.

Very few wells in the basin have been drilled deep enough to penetrate the limestone formations of the Trenton Group; those that do are usually reported dry and subsequently abandoned. Poor ground-water availability also characterizes the Collingwood, Meaford-Dundas, Blue Mountain, and Queenston shales.

The irregular topography of the bedrock surface, and in particular the Niagara Escarpment, seems to have a marked influence on the scale and direction of the ground-water flow patterns in the overburden above the escarpment. Probably the most significant effects on ground water are : 1) to increase the depth to the water-table adjacent to the escarpment, and 2) to interrupt or terminate flow patterns in the overburden.

Undoubtedly at some distance west of the escarpment there is a subsurface divide between east- and west-flowing ground-water systems in the bedrock. Such a divide is indicated by Johnston (1964, p. 18) in the vicinity of Niagara Falls, N.Y.

Amabel Formation

The Amabel Formation is about 160 feet thick and subcrops beneath the overburden in the western-most portion of the watershed. Almost all drilled wells in this area derive their water from relatively shallow crevices and fractures close to the overburden-dolomite contact. Average yields from this formation are in the order of 10 to 20 gpm. Often the yields can be increased to more than 100 gpm by penetrating greater thicknesses of the crevassed rock. Two municipal wells at Shelburne have penetrated 42 and 58 feet of dolomite, and each has an estimated theoretical yield* of 700 gpm, which is not exceptional for this formation. However, each well can yield only about 100 gpm.

Most of the wells ending in the Amabel dolomite are between 50 to 100 feet deep, and the majority of the domestic wells penetrate 20 to 30 feet of bedrock before obtaining adequate water for supplies. Deeper penetrations into the rock normally have the effect of increasing the yields, and individual well yields of 50 to 100 gpm do occur.

There is a pronounced difference in yields between the high-yield area underlain by the Amabel dolomites and the low-yield area underlain by the Queenston shales (Figure 11). The average theoretical yield for the Queenston shales is about 2 gpm, and very often the actual yields are less than 1 gpm, which is barely enough to satisfy conservative domestic uses.

Ground-Water Occurrence in Overburden

Overburden covers most of the bedrock east of the escarpment, and its thickness ranges mainly between 200 to 300 feet. However, one well in the eastern portion of the basin has penetrated more than 500 feet of overburden before encountering limestone. The overburden composition is highly variable, but because of the large thickness of unconsolidated drift available for ground-water exploration, the chances of locating water-bearing formations are generally good. The prediction of exact aquifer locations and extent is difficult because the history of deposition of the deep subsurface formations is relatively unknown. Geologic data, however, are sufficient to permit the grouping of significant water-bearing materials in the overburden into aquifer units (Map 2743B-5).

Kame, Outwash Complex

Thick, continuous surficial kame and outwash deposits of sand and gravel are located just east of the escarpment and along the southwestern drainage basin divide. Although kame deposits usually consist of gravel, sand predominates in many of the kame hummocks throughout the basin. Outwash deposits are composed mainly of sand with small amounts of interbedded gravels.

At most localities the sand and gravel deposits are thick, often 100 feet or more in kame areas and generally 30 to 40 feet in most outwash deposits. The unconfined outwash deposit of sand south of Tottenham is reported to be as thick as 170 feet (Figure 12). The thinnest outwash deposits consist of gravel in the channels located on the plain adjacent to the upper portions of the Nottawasaga and Boyne rivers. Here the gravels are only about 10 feet thick.

Most of the thick kame and outwash deposits are unconfined, and the depth to the water-table varies according to topography. In the areas of high relief east of the escarpment,

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$$\text{*Theoretical Yield (gpm)} = \frac{\text{test pumping rate (gpm)} \times \text{available drawdown (ft)}}{\text{drawdown (ft)}}$$

Theoretical yields have been calculated for comparative purposes only and do not indicate "actual" yields that can be sustained from wells.

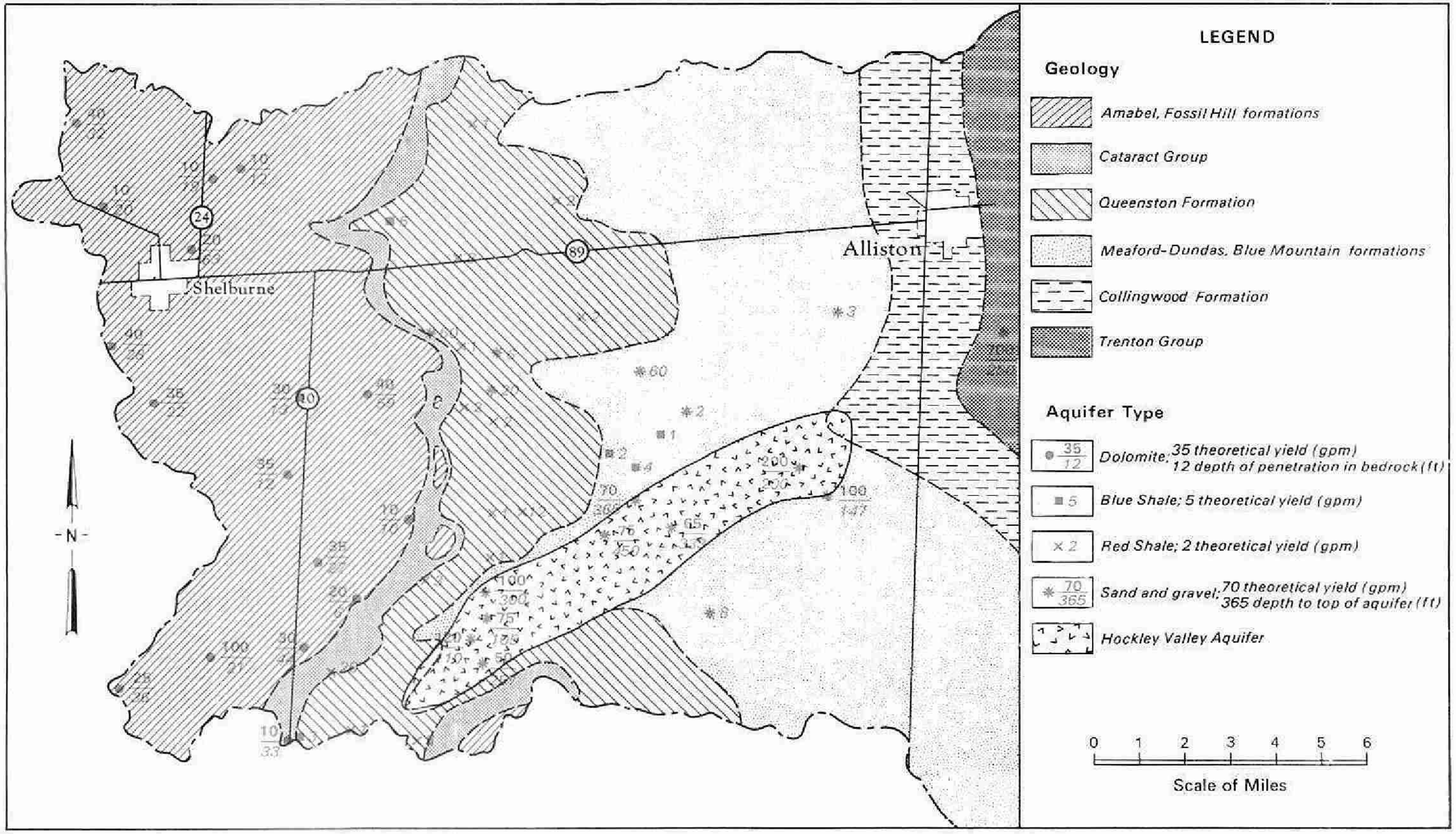
LEGEND
Geology
Amabel, Fossil Hill formations
Cataract Group
Queenston Formation
Meaford-Dundas, Blue Mountain formations
Collingwood Formation
Trenton Group
Aquifer Type
Dolomite; 35 theoretical yield (gpm) 12 depth of penetration in bedrock (ft)
Blue Shale; 5 theoretical yield (gpm)
Red Shale; 2 theoretical yield (gpm)
Sand and gravel; 70 theoretical yield (gpm) 365 depth to top of aquifer (ft)
Hockley Valley Aquifer
0 1 2 3 4 5 6
Scale of Miles
Shelburne
Alliston
24
89
10
- N -

Figure 11. Theoretical yield of wells in bedrock and deep overburden formations adjacent to the Niagara Escarpment.

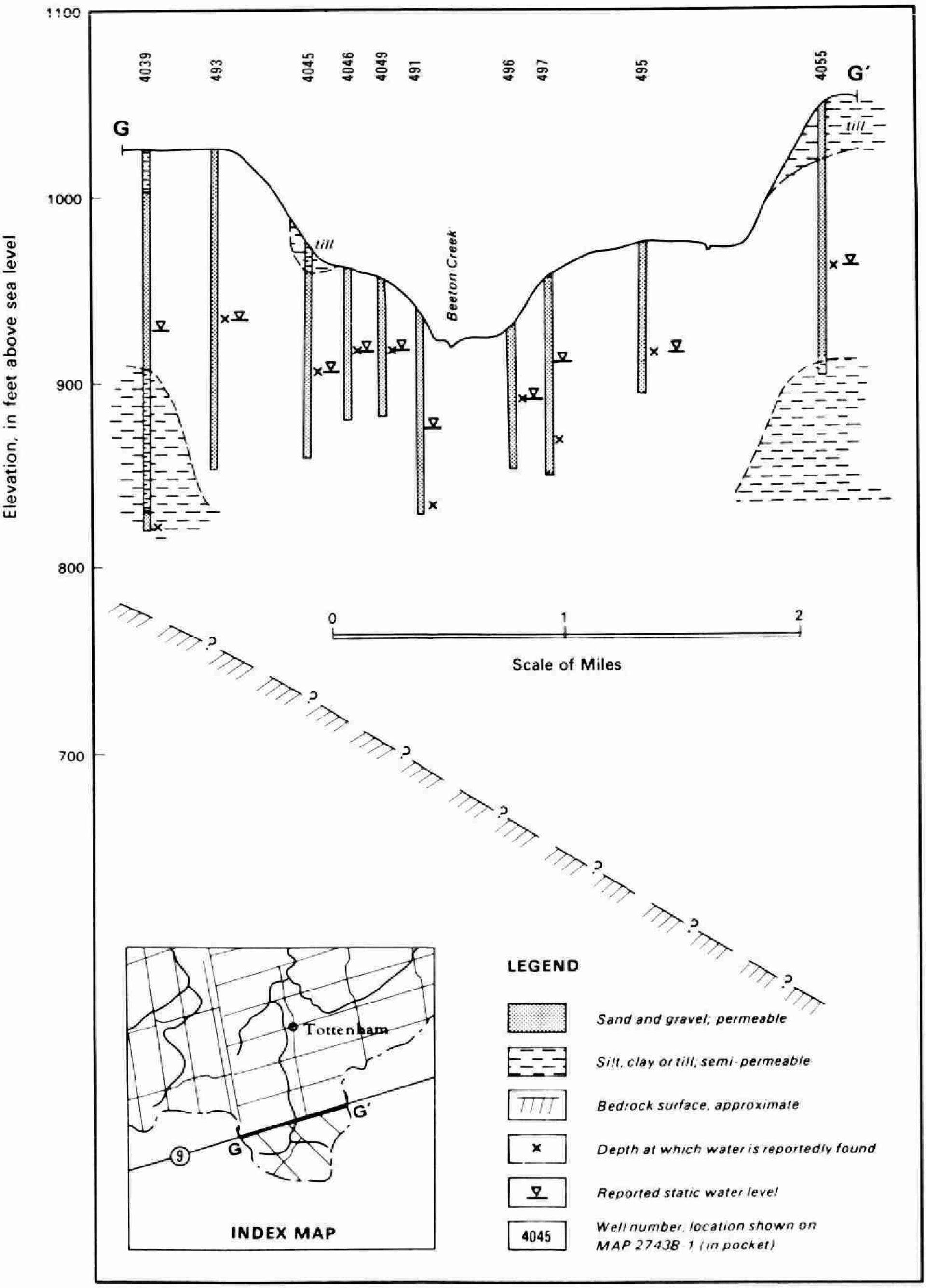
1100
1000
900
800
700
Elevation, in feet above sea level
4039
493
4045
4046
4049
491
496
497
495
4055
G
G'
till
till
Beeton Creek
?
0
1
2
Scale of Miles
LEGEND
Sand and gravel; permeable
Silt, clay or till; semi-permeable
Bedrock surface, approximate
Depth at which water is reportedly found
Reported static water level
4045
Well number, location shown on MAP 2743B-1 (in pocket)
Tottenham
9
G
G'
INDEX MAP

Figure 12. Cross-section G-G' through outwash deposits south of Tottenham, illustrating the continuity and thickness of the sand and gravel deposits. Note the deep static levels.

the water-table is often more than 50 feet deep; in the relatively low relief areas of kame terrace and outwash deposits the average depth to water is about 20 feet. Water-table depth can often be inferred from the type of well construction; dug wells generally indicate shallow water-table conditions, whereas drilled wells are indicative of deep water-table areas. For example, the majority of wells in the outwash deposit north of Cedarville and Connor are dug to depths of 20 to 30 feet and they intersect the water-table at depths of 25 feet or less. On the other hand, almost all wells located in the outwash deposit south of Tottenham are drilled wells which intersect the water-table at depths greater than 40 feet.

The theoretical yields of wells in these surficial deposits are usually less than 5 gpm. Proper screening of the formation and well development may increase the yield to at least 5 gpm, and in certain semi-confined formations, yields as high as 50 gpm have been obtained.

Recharge of water to the surficial formations is by the infiltration of local precipitation. Much of the water that is added to ground-water storage is discharged into local streams that deeply dissect the sand and gravel deposits. Because of the great thicknesses of ice-contact material at the base of the escarpment, the area covered by these deposits is considered to be a major recharge area for confined aquifers in the eastern portions of the basin.

Till Complex

Till is considered to be a semi-permeable deposit incapable of transmitting large quantities of water, but the sand till in the basin does transmit sufficient quantities of water for domestic use. Shallow dug or drilled wells in the till-plain areas derive water from three sources (Figure 13): 1) from the sand till formation; 2) from sand or gravel lenses in the till, and 3) from sand and/or gravel deposits of lacustrine or ice-contact origin beneath the surface till. Wells obtaining water from the sand till or from small sand lenses in the till should be of large diameter to provide sufficient storage to sustain high rates of withdrawals. Underlying much of the till plain south and southeast of Beeton are sands and gravels of ice-contact and lacustrine (Lake Schomberg) origin which normally have better water-yielding characteristics than the till. These deposits are seen to outcrop from beneath the till in numerous gravel pits and road cuts between Beeton and Tottenham.

On the northern till plains, the chances of obtaining adequate ground-water supplies from shallow depths are poor and most wells must penetrate the till cover to obtain water from underlying lacustrine sands.

Surficial till thicknesses vary from a few feet at localities near the southern basin boundary, to about 60 feet in areas north of Cookstown where the till cover is generally the thickest.

Well yields from till are small — generally only a few gpm. In most till plain areas, there are no problems of obtaining adequate domestic water supplies, except where poor well construction or inadequate well development in a till formation results in insufficient supplies during periods of low water levels in the summer and fall. Supplies in excess of about 20 gpm from shallow wells in till should not be expected.

Lake Algonquin Sand Aquifer

Fine- to medium-grained sand deposits of glacial Lake Algonquin occur below a surface elevation of 750 feet, and form an unconfined (water-table) aquifer throughout the sand plain in the basin. The thickness of this surface sand is variable but reaches about 80 feet in areas north of Alliston. Most wells indicate a thickness in the order of 40 feet (Figure 14).

Average theoretical yields from the aquifer are about 5 gpm. In many instances the actual yields are restricted to smaller quantities by the limited thickness of saturated sand. A disadvantage of the water-table aquifer is that during periods of low rainfall, the natural decline of the water-table will decrease the thickness of the zone of saturation and consequently the yield of wells. The water-table in the sand plain area varies from a high during the spring to a low in late fall, but is usually less than 15 feet deep throughout the year.

Southwest of Alliston on the plain of the Nottawasaga River and southwest of Everett on the plain of the Boyne River, the surface sand grades into outwash gravels which have been included in the aquifer unit. At most localities the gravel deposit is thin. In some areas shallow wells produce sufficient water for domestic purposes from the thin deposits, but in many cases deeper wells may be required.

The major source of recharge to this unconfined aquifer is infiltration of rain during the summer, and of snowmelt during the spring.

Thornton Sand Aquifer

Underlying the till plain north of Cookstown is a sand aquifer whose extent can be defined, in part, by the 850-foot elevation which represents the top of the formation (Figure 15). The sand is reported to be medium- to coarse-grained, does not contain any gravel, and is part of a thick sequence of confined lacustrine deposit of sand, silt, and clay in the area. The reported thickness of the sand varies from a few feet to at least 26 feet. A similar sand formation, located in a lacustrine sequence near Fennell on Highway 11, may be an eastward extension of this deposit. Here the top of the sand is at an approximate elevation of 800 feet, and the depths of all the static levels are in the order of 100 feet.

Most of the static water levels in the main formation (north of Cookstown) are between 70 and 100 feet deep, which suggests, in part, a low rate of recharge through the overlying till. The sand formation and the overlying till are elevated above the surrounding land surface, and consequently, subsurface recharge from outside the area is unlikely.

Due to small available drawdowns, the theoretical yields of the aquifer are less than 10 gpm, which is adequate for rural domestic purposes. Yields in excess of 25 gpm may be obtained where the formation is at least 20 feet thick.

Alliston Sand Aquifer

A deep, confined sand aquifer underlies most of the eastern portion of the basin where the bedrock elevation is generally less than 500 feet (Figure 16). The sand seems to be part of a deep lacustrine formation that extends south towards Lake Ontario and north towards Georgian Bay. It is usually reported as medium- to coarse-grained and is often overlain by a "blue clay" deposit about 40 feet thick, or by a thick deposit of silt and clay, some of which may be glacial till. At many locations the sand is interbedded or replaced by sequences of silt or very fine sand ("quicksand").

At elevations of 500 feet or higher, the deposit is mostly coarse-grained and usually about 10 to 20 feet thick. Below 450 feet, the sand is generally fine- to medium-grained and thicknesses up to 80 feet have been reported in well logs.

The highest reported head elevation in the aquifer is about 785 feet, and the lowest approximately 730 feet. Most are in the order of 750 feet. Flowing wells in the formation occur commonly when the well-collar elevations are less than 750 feet (Map 2743B-5).

The majority of domestic wells penetrate only a few feet of the sand formation, and hence, most of the theoretical yields are less than 5 gpm. However, yields to properly constructed wells can be increased to at least 100 gpm when larger thicknesses of the formation are penetrated. For example, one Alliston municipal well (4236) is screened over 24 feet in the sand and has a theoretical yield of 1000 gpm. The rated capacity of the well is about 350 gpm.

As the piezometric surface in the aquifer does not conform to the topographic expression of the local land surface, recharge to the aquifer is not local. Two possible areas of recharge are the kame moraine and terrace areas east of the escarpment, and the Oak Ridges moraine near the southeastern boundary of the basin.

Hockley Valley Aquifer

Elevation contours on top of the bedrock surface (Map 2743B-3) suggest a bedrock valley underlying the Nottawasaga River in the region of Hockley Valley and its extension to the

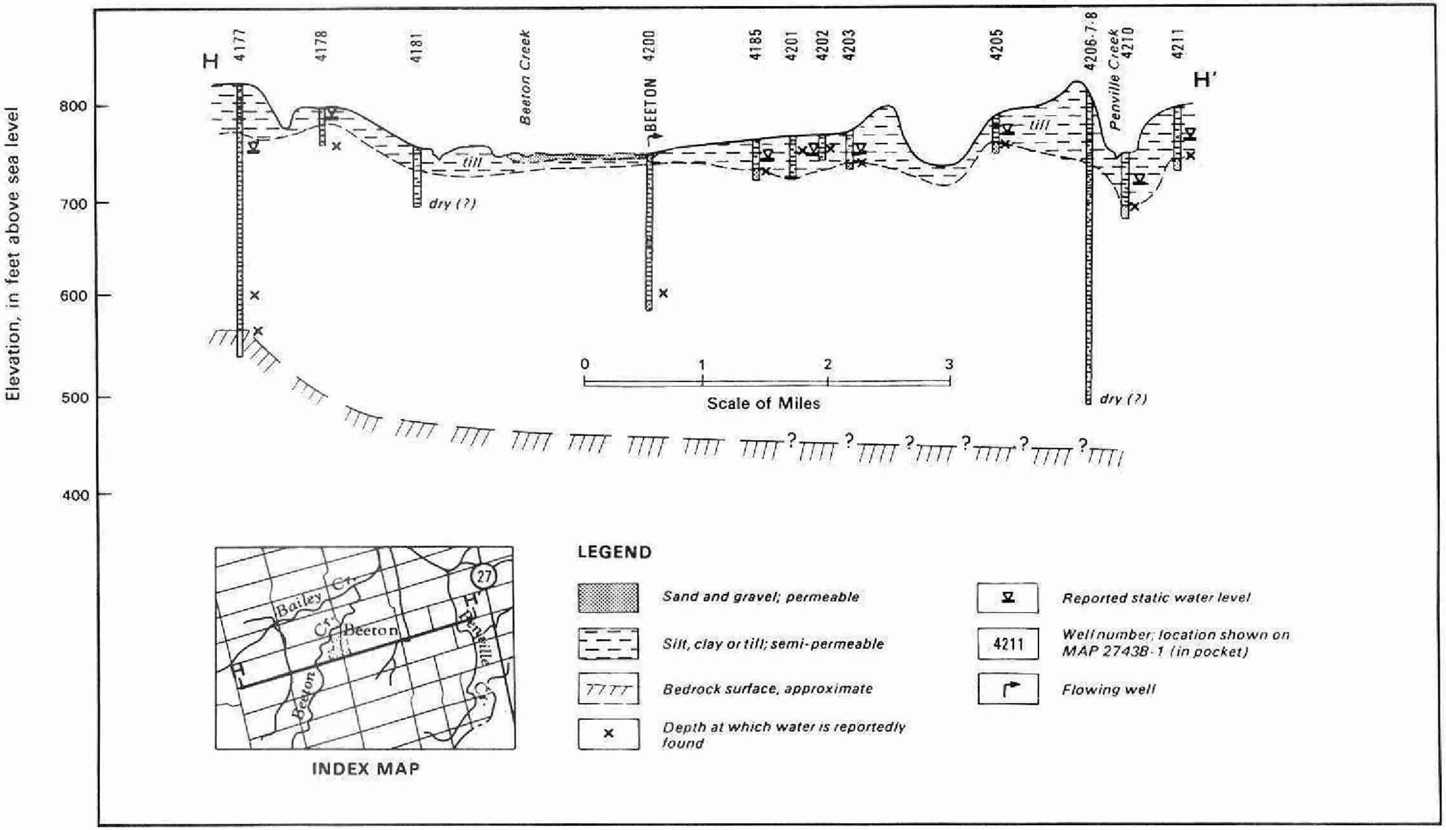
H
4177
4178
4181
Beeton Creek
4200
BEETON
4185
4201
4202
4203
4205
4206-7-8
Penville Creek
4210
4211
H'
Elevation, in feet above sea level
800
700
600
500
400
till
till
till
dry (?)
dry (?)
?
0
1
2
3
Scale of Miles
Bailey Cr.
Beeton
Beeton Cr.
Penville Cr.
27
H
H'
INDEX MAP
LEGEND
Sand and gravel; permeable
Silt, clay or till; semi-permeable
Bedrock surface, approximate
Depth at which water is reportedly found
Reported static water level
4211
Well number; location shown on MAP 2743B-1 (in pocket)
Flowing well

Figure 13. Cross-section H-H' illustrating the shallow hydrogeology associated with the surficial till near Beeton. Many wells derive water from ice-contact gravels directly beneath the till.

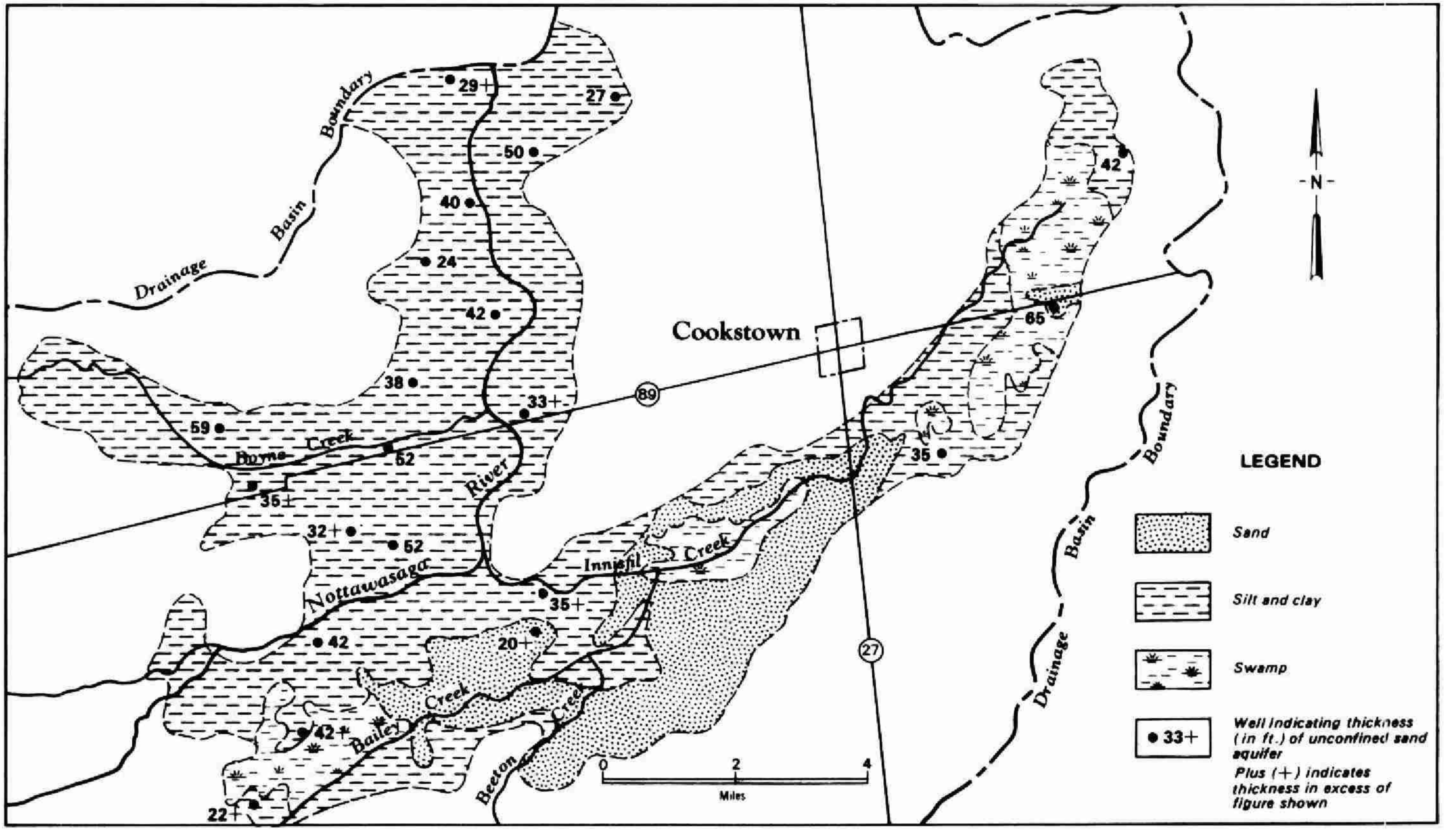

Figure 14. Approximate thickness of the surficial Lake Algonquin sand aquifer in the Upper Nottawasaga River basin.

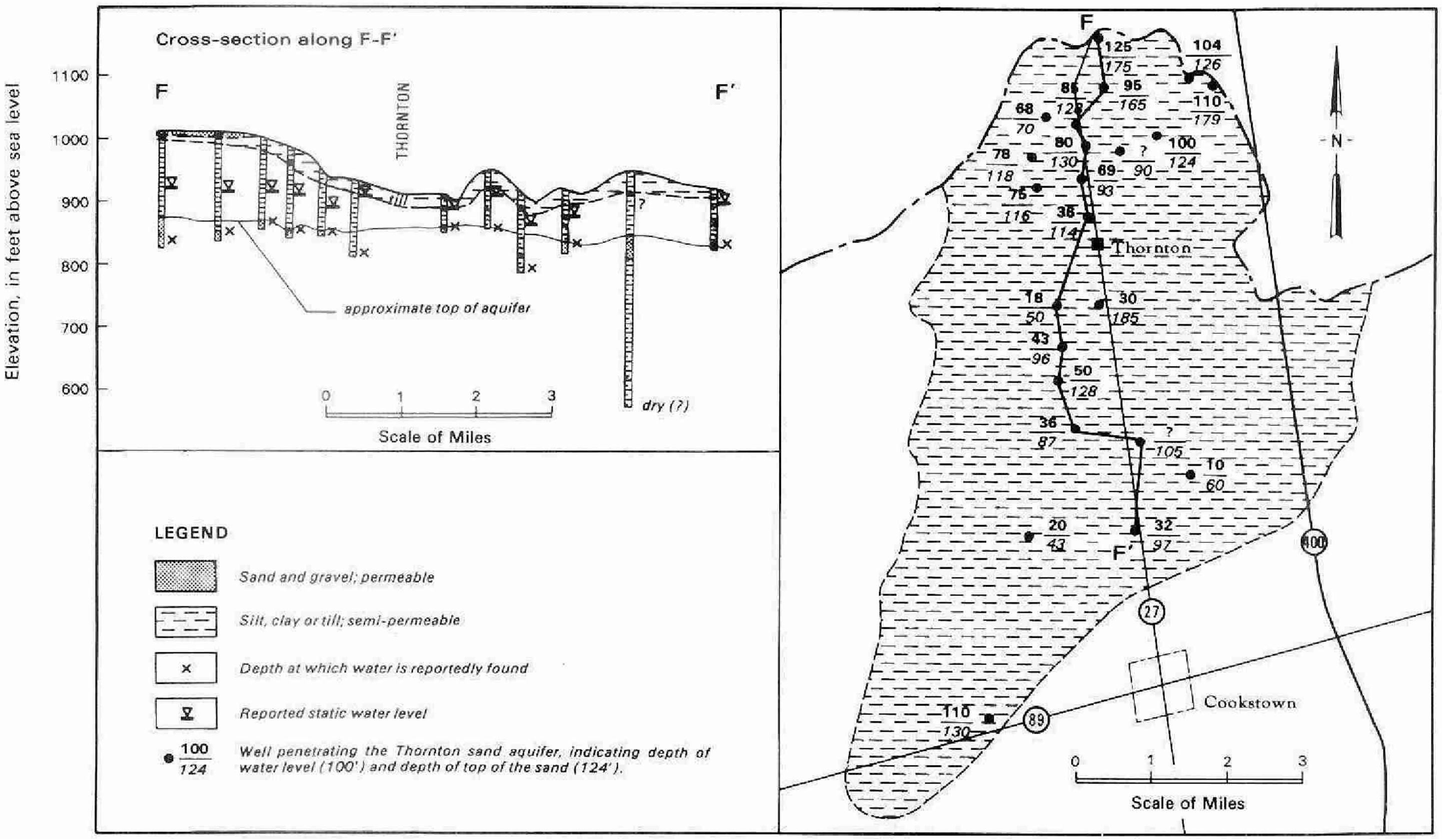

Figure 15. Hydrogeology of the Thornton sand aquifer.

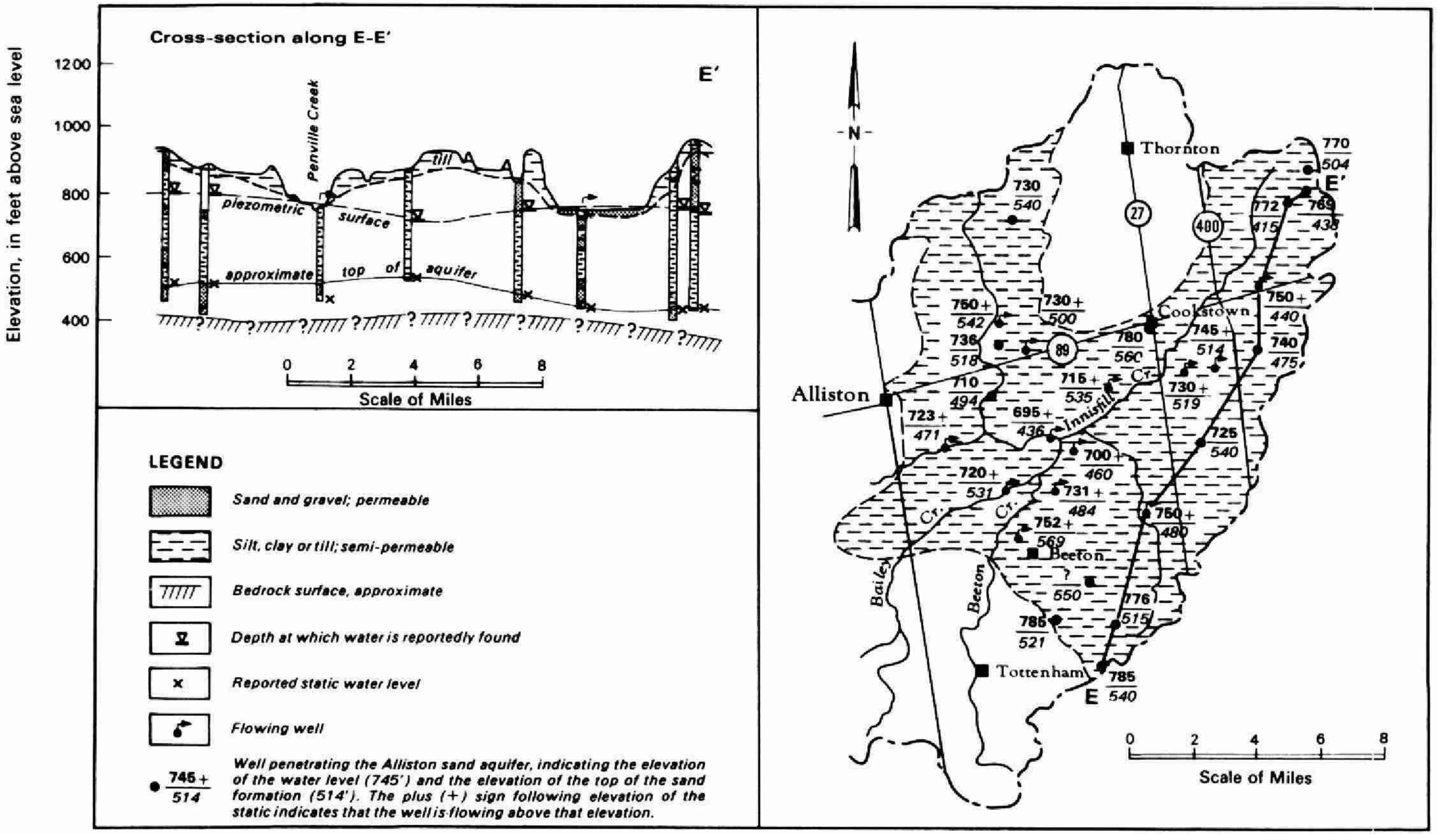
Cross-section along E-E'
Elevation, in feet above sea level
1200
1000
800
600
400
E'
Penville Creek
till
piezometric surface
approximate top of aquifer
0 2 4 6 8
Scale of Miles
LEGEND
Sand and gravel; permeable
Silt, clay or till; semi-permeable
Bedrock surface, approximate
Depth at which water is reportedly found
Reported static water level
Flowing well
745+
514
Well penetrating the Alliston sand aquifer, indicating the elevation of the water level (745') and the elevation of the top of the sand formation (514'). The plus (+) sign following elevation of the static indicates that the well is flowing above that elevation.
N
Thornton
Cookstown
Alliston
Beeton
Tottenham
27
400
89
Innisfil Cr.
Cr.
Cr.
Bailey
Beeton
E
E'
0 2 4 6 8
Scale of Miles

Figure 16. Hydrogeologic details of the Alliston sand aquifer. Note the numerous flowing wells associated with this aquifer.

northeast. The head of the bedrock valley is notched into the Niagara Escarpment, and Straw (1968) believes this valley was the result of glacial erosion. Fluvial deposits have not been found on top of the bedrock at the head of the valley; however, farther down the valley sand and gravel located close to the bedrock surface (as in wells 571 and 62) may suggest fluvial origin.

Overburden thickness in the valley ranges from zero, where the bedrock outcrops along the banks of the Nottawasaga River, to 475 feet as revealed by well 571 northwest of Hockley. Theoretical yields of wells in the sand and gravel aquifer are in the order of 75 gpm; well 137 in Adjala Township has a theoretical yield of 450 gpm from a sand aquifer 200 feet deep. A properly developed, fully penetrating well drilled in the confines of the valley should readily yield 100 gpm from sands and gravels.

Piezometric Gradients

During the 1968 field season, piezometer "nests" were installed at seven sites to determine the vertical head gradients in the Lake Algonquin sands, in the sand till, and in confined lacustrine formations. The geologic logs at each nest are shown in Appendix A. Head measurements obtained from these piezometers were used to determine directions of ground-water flow, and to estimate the coefficients of permeability (k) of the formations opposite the piezometer screens (Table 4). During the permeability tests by the Hvorslev (1951) method, hydrostatic time lags* were calculated to evaluate the response of each piezometer to natural changes in formation pressures, and thereby, where necessary, to correct the observed head values. However, because the time lags were small, corrections to observed readings were insignificant.

Table 4. Calculated Basic Hydrostatic Time Lags and Coefficients of Permeability of Overburden Materials in the Upper Nottawasaga River Basin

Piezometer Nest	Screen Depth (ft)	Material	Basic Time Lag (T) (min)	Coefficient of Permeability (k)	
				in/min	cm/sec
260	40	silt	3	2×10^{-2}	1×10^{-3}
	70	silt till	15	4×10^{-3}	2×10^{-4}
	127	silt	50	1×10^{-3}	1×10^{-5}
261	34	sand	1.5	4×10^{-2}	2×10^{-3}
262	40	silt	7	8×10^{-3}	4×10^{-4}
	71	clay till	50	1×10^{-5}	4×10^{-5}
	133	sand	no test	no test	no test
263	46	sand	0.8	6×10^{-2}	2×10^{-3}
264	44	silt till	142	3×10^{-4}	1×10^{-5}
	75	clay	490	1×10^{-4}	1×10^{-6}
	113	clay	105	5×10^{-4}	2×10^{-5}
265	42	sand	0.7	7×10^{-2}	3×10^{-3}
266	28	clay	65	3×10^{-4}	1×10^{-5}
	52	clay till	890	6×10^{-6}	2×10^{-7}
	81	sand	3	2×10^{-2}	1×10^{-3}
	142	silt till	30	2×10^{-3}	1×10^{-4}

**Hydrostatic time lag* is defined as "The time required for water to flow to or from a device until a desired degree of pressure equalization is attained. . . ." (Hvorslev, 1951).

The vertical component of flow at piezometer nest sites 260, 262, 264, and 266 is downward throughout the year (Table 5); at nest 262 the downward gradient between the 40- and 71-foot depths is insignificant.

Table 5. Calculated Vertical Hydraulic Gradients in Piezometer Nests in the Upper Nottawasaga River Basin, on November 12, 1968, and April 8, 1969

Nest	Depth (ft)	Downward Gradient							
		November 12			Avg.	April 8			Avg.
260	13 40 70 127	0.4	0.04	0.04	0.1	0.4	0.05	0.04	0.1
262	14 40 71 133	0.05	nil	1.5	0.8	0.08	nil	1.5	0.8
264	24 44 75 113	?	0.8	0.2	0.4	0.2	1.5	0.2	0.6
266	28 52 81 142	0.5	0.2	0.08	0.2	0.5	0.2	0.1	0.2

The average head decrease, in feet per foot of overburden depth, ranged from 0.1 to 0.8. For the well drilled at site 260, the decrease in water level, per foot of depth of well below the water-table, is about 0.1 feet, and for the well drilled at site 262, it is about 0.8 feet.

The vertical gradients are small at sites 261, 263, and 265, and indicate a more significant lateral than a vertical movement of water in the sand.

Water-Level Fluctuations

Fluctuations of the water-table and the piezometric surface indicate changes in groundwater storage. The history of such changes can be used to determine the depletion of water storage in an aquifer, the fluctuation characteristics of the water-table or the piezometric surface, and to study the seasonal recharge characteristics to an aquifer.

Two abandoned dug wells, each equipped with a water-level recorder, were used to observe water-level fluctuations in an unconfined and a confined aquifer. The Alliston observation well (Map 2743B-2) is 19 feet deep and indicates water-table fluctuations on the broad Lake Algonquin sand aquifer. The Cookstown observation well penetrated approximately 40 feet of sand till to encounter a water-bearing sand layer.

Water-level records at both wells reveal ground-water depletion throughout the summer months; recharge to storage occurs mainly during the spring (Figure 17). The water level in the unconfined aquifer was much more sensitive to local precipitation than in the confined formation, but the unconfined aquifer had a smaller annual amplitude of water-level change.

The rate of natural infiltration and percolation of precipitation at the Alliston observation-well site was calculated from measurements of precipitation at the site during the summer of 1968. Rates of water movement (through the unsaturated zone; unknown antecedent soil-moisture conditions) of 3.0 to 3.5 inches per hour occurred on three separate occasions in September and October. On each occasion, the water-table was about 14 feet below ground surface.

A similar study at the Cookstown observation-well site showed no discernable water-level response to local rainfall during the period of study from July to the beginning of September 1968. This indicates a lack of recharge of water to the confined sand during this period.

The fluctuations of water levels in piezometers in nests 260, 263, and 266 are shown in Figure 18. For the most part, the water-level fluctuations are self-explanatory. The water-level trends in these piezometers indicate that net recharge* to ground-water storage occurs from fall through to late spring, and net discharge* takes place from late spring to the following fall. Water-level fluctuations in the deeper formations (such as at piezometer 266-142) are smaller than those in the overlying formations.

The smallest water-level changes during the 1968-69 observation period occurred in piezometers in nests 261, 263, and 265; all are constructed in surface sands. The maximum annual fluctuation in these piezometers was about four feet. The largest fluctuation, in excess of 24 feet during the same period, occurred in piezometer 264-44 which is finished in silt till.

Surface Water

Introduction

Surface water forms an integral part of the water balance and the hydrologic cycle on the earth's surface. Together with ground water, surface water in streams, lakes, and reservoirs is a resource which requires management to ensure that its natural quality and role in the hydrologic cycle is maintained. Before formulating management plans, however, an inventory of the resource is essential. To this end, evaluation of the resource is made in terms of the quantity and distribution of surface water in the basin.

Field work consisted of stream-gauging during the summer of 1968, together with the establishment of three permanent, recording stations, and the sampling of stream water for chemical analysis. As the resource evaluation is primarily for inventory purposes, discussions relate mainly to generalities of flow amounts and time variations in the Nottawasaga River and its larger tributaries. Included in these discussions are analyses of high and low flows, flow-frequency determinations, and estimates of runoff yields from various parts of the basin.

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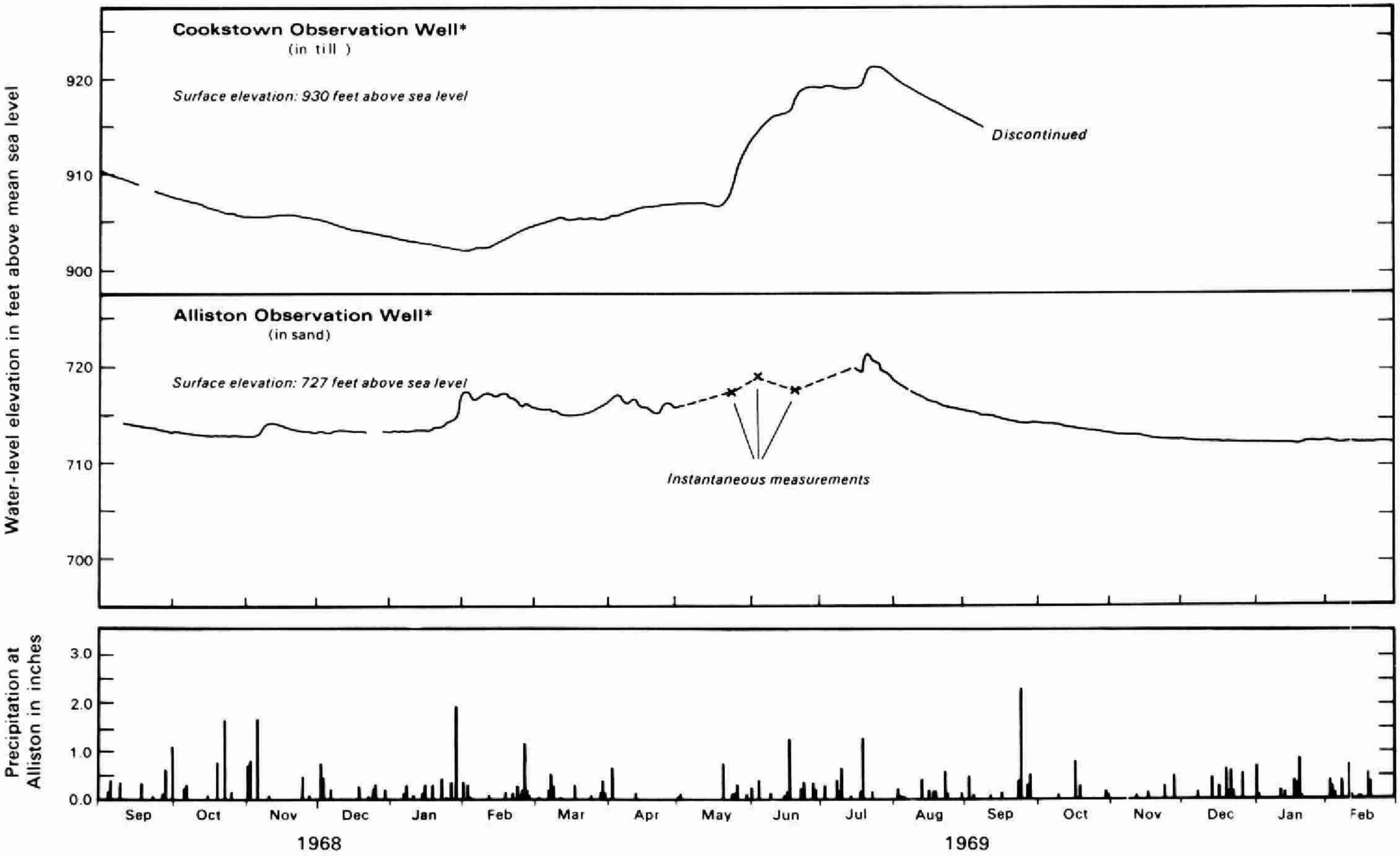
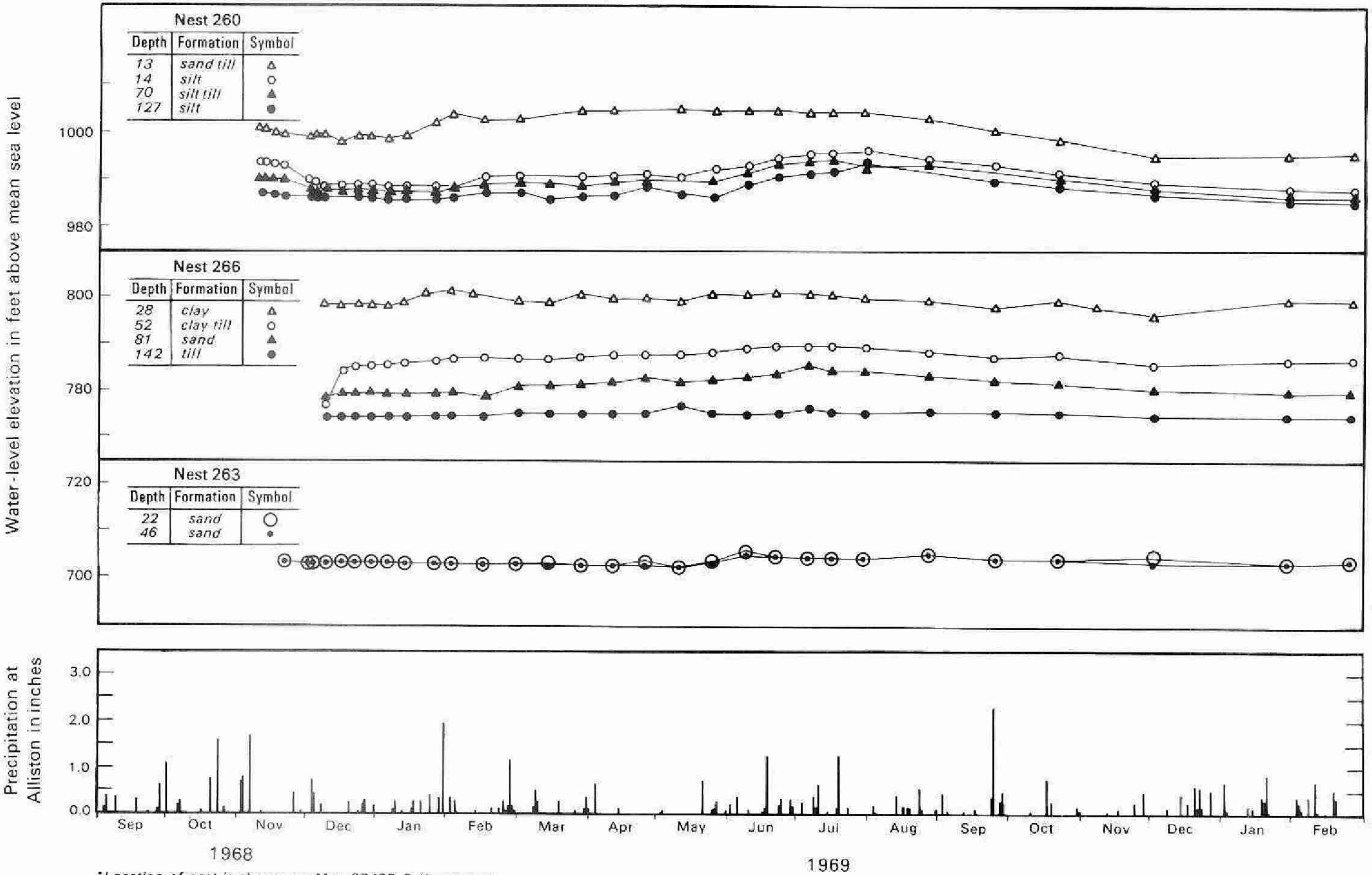
* *net recharge* occurs when the rate of recharge to storage exceeds the rate of discharge; *net discharge* occurs when the rate of discharge from storage exceeds the rate of recharge.



*Location of well is shown on Map 2743B-2 (in pocket)

Figure 17. Precipitation at Alliston and water-level hydrographs for two continuous-recording observation wells, Upper Nottawasaga River basin, for the period July 1968 to December 1969.



*Location of nest is shown on Map 2743B-2 (in pocket)

Figure 18. Precipitation at Alliston and water-level hydrographs for three piezometer nests, Upper Nottawasaga River basin, for the period July 1968 to December 1969.

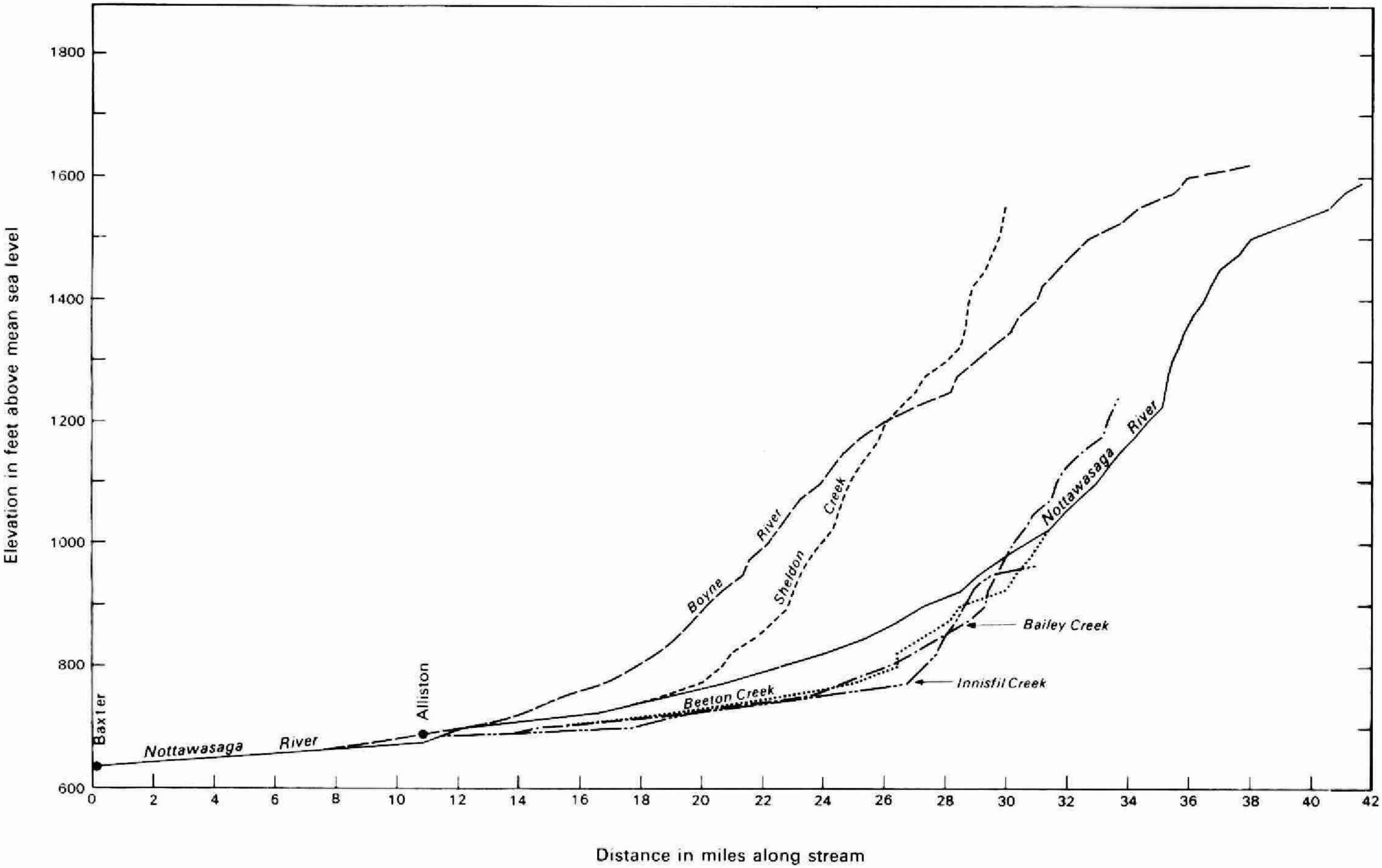


Figure 19. Stream profiles, Upper Nottawasaga River basin.

Physiographic Description of Streams

The main stream in the basin is the Nottawasaga River, and the largest tributaries are Innisfil Creek, the Boyne River, and Sheldon Creek. The main tributary of Innisfil is Bailey Creek. The Boyne River and Sheldon Creek do not have significantly large tributaries.

The headwaters of the Nottawasaga River originate in swamps in the Escarpment Upland physiographic region where they flow sluggishly over undulating terrain. The streambed gradient of the Nottawasaga River (Figure 19) is largest as it flows over the escarpment into the Kame Hills physiographic region and decreases gradually throughout the Sand Plain region. The total length of the Nottawasaga River in the basin is 42 miles (Table 6), with an average streambed gradient of approximately 23 feet per mile.

Table 6. Physical Characteristics of Streams in the Upper Nottawasaga River Basin

Stream	Streamflow Gauging Station*	Length Above Station (mi.)	Area Drained Above Station (sq. mi.)	Drop Above Station (ft.)
Nottawasaga River	2ED-3	42	469	955
Boyne River	10	30	85	960
Innisfil Creek	18	20	183	285
Bailey Creek	2ED-4	20	82	550
Sheldon Creek	29	13	33	874

*The location of the stations is shown on Map 2743B-2.

The Boyne River (Plate 9) flows through the same physiographic regions as the Nottawasaga River and joins it about three miles downstream from Alliston. The length of the Boyne River is 30 miles and it has an average streambed gradient of 32 feet per mile. The gradient is steep throughout the upper two-thirds of its length, but decreases sharply on the Lake Algonquin sand plain.

Innisfil Creek sub-basin drains slightly more than one-third of the total area of the basin and contains the main stream and several large tributaries. Innisfil Creek itself is only 20 miles long and its streambed is confined entirely to the Lake Algonquin sand plain. Its average streambed gradient is only about 14 feet per mile. Bailey and Beeton creeks together drain about 82 square miles (45 per cent) of the Innisfil Creek sub-basin and indicate the runoff characteristics of the southern till plain area. Bailey Creek has a total length of 29 miles and an average streambed gradient of 27 feet per mile.

Sheldon Creek is the smallest of the major tributaries, with a length of only 13 miles but an average streambed gradient of 67 feet per mile. This gradient is the largest of all the streams in the basin because most of the stream is located in the high-relief terrain of the Kame Hills physiographic region. The area drained by Sheldon Creek is 33 square miles.

Surface-Water Data

Streamflow data in the basin were collected from five recording stations (Table 7). Three of the five stations were installed during the study period in 1968 and therefore provided only short-term records for this investigation. Two stations were installed prior to 1968 and are operated by the Water Survey of Canada. The oldest of the two, established in 1947, is on the Nottawasaga River near Baxter (2ED-3) and records streamflow out of the basin. The data from the five recording stations were supplemented by periodic streamflow measurements during the period from May to September 1968, at 25 locations shown on Map 2743B-2.

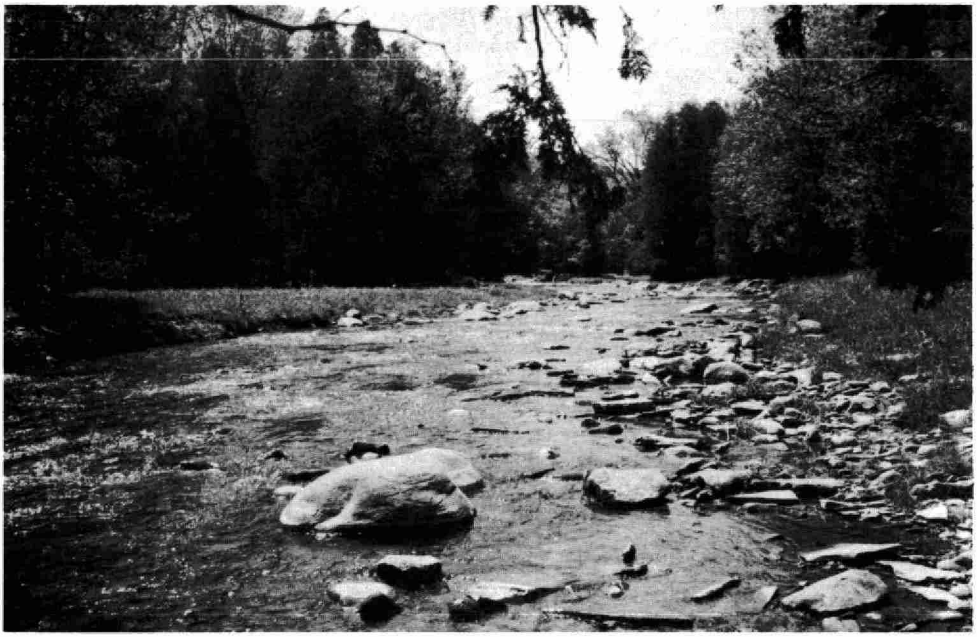


Plate 9. Boyne River near Perm Hall, looking upstream; note the steep streambed gradient.

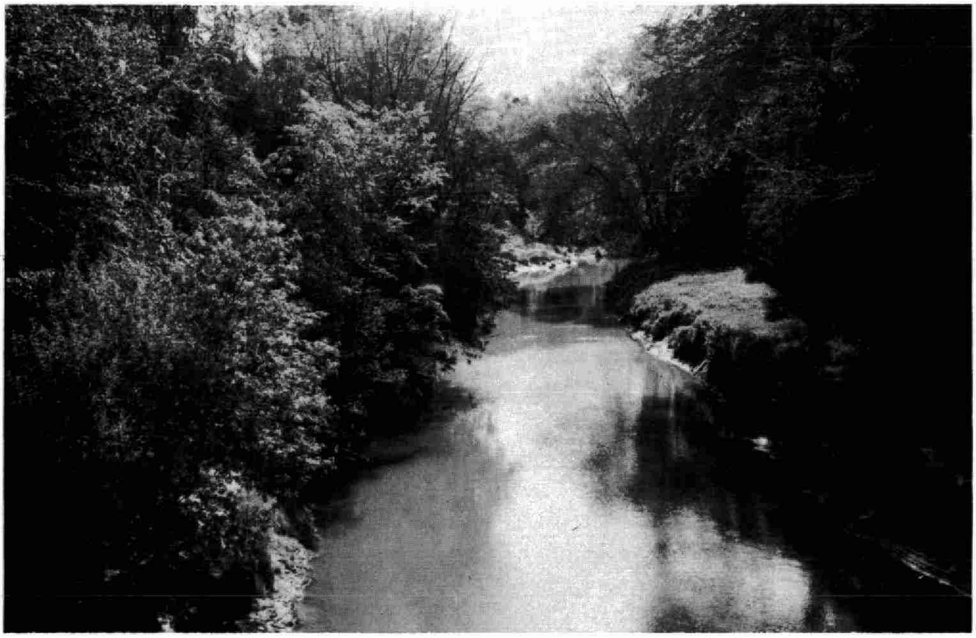


Plate 10. Innisfil Creek north of Allimil, looking downstream; note the well-defined channel.

Table 7. Streamflow Gauging Stations, Upper Nottawasaga River Drainage Basin

Station Number	Name of Station	Drainage Area (sq. mi.)	Gauge Location† a) Lat. b) Long.	Period of Record	Type of Gauge	Operation	Data on Magnetic Tape
2ED-3	Nottawasaga R. near Baxter	469	a) 44° 14′ 59″ b) 79° 49′ 20″	1947-48	Manual	Seasonal	Yes
				1949-64	Manual	Continuous	Yes
				1965-70	Recording	Continuous	Yes
2ED-4	Bailey Creek near Beeton	82	a) 44° 07′ 08″ b) 79° 45′ 43″	1963-70	Recording	Continuous	Yes
2ED-100*	Beeton Creek near Tottenham	33	a) 44° 00′ 35″ b) 79° 45′ 38″	1968-70	Recording	Continuous	No
2ED-101*	Nottawasaga R. above Alliston	129	a) 44° 05′ 20″ b) 79° 50′ 40″	1968-70	Recording	Continuous	No
2ED-102*	Boyne River at Earl Rowe Park	82	a) 44° 05′ 49″ b) 79° 50′ 50″	1968-70	Recording	Continuous	No

* Operated by OWRC
† See Map 2743B-2

Streamflow Hydrographs

The time variation of streamflow in the Nottawasaga River at the Baxter gauge is discussed in terms of mean monthly streamflow, average monthly streamflow during a consecutive 10-year period (1959 to 1968), and in terms of daily hydrographs for the years 1958, 1967, and 1968. Only data at the Baxter gauge were used in these analyses because this is the only station in the basin with a sufficiently long period of record.

The long-term mean monthly streamflow at Baxter is based on 19 years of record. During this period, mean flows in March and April have been considerably higher than the rest of the year (Figure 20). The combined flows for these two months account for 44 per cent of the average annual discharge out of the basin. The lowest mean monthly flow occurs in August.

The largest annual peaks occur in the spring but vary in magnitude from year to year. The largest peak in the period 1959 to 1968 occurred in April 1960, when the monthly discharge at Baxter averaged 2170 cfs, and the smallest peak was recorded in April 1964, when the average discharge was only 420 cfs (Figure 21). Unusually high flows during June and July of 1967 were produced by abnormally high precipitation. Rainfall of 11.28 inches at Beeton during June of this year was almost five times the normal for this month.

Daily streamflow hydrographs for the 1958, 1967, and 1968 water years are presented to compare streamflow during years of below normal, normal, and above normal precipitation in the basin (figures 22, 23, and 25). During the 1967 water year the precipitation at Beeton was 7.3 inches above normal, while precipitation during the 1958 water year was 7.5 inches below normal. Normal precipitation at Beeton is 30.82 inches.

Two features are noticeable in streamflow during the 1958 and 1967 water years. For one, the spring peak runoff in 1967 was almost twice as large as that in 1958. The second feature is the unseasonably high flows that resulted from almost 19 inches of rainfall during June, July, and August 1967. Streamflows during the summer of 1967 did not recede below 100 cfs, whereas in 1958 the low summer flow was in the order of 55 cfs.

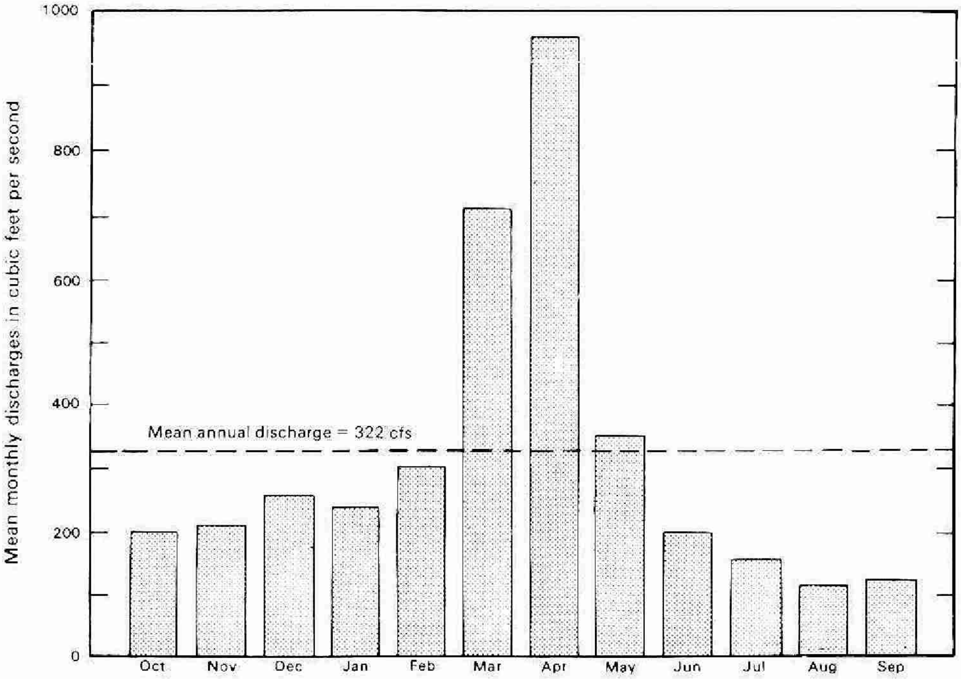


Figure 20. Mean monthly streamflow hydrograph, Nottawasaga River near Baxter, based on 19 years of record (1950–1968).

The streamflow hydrograph for the 1968 water year was separated into two components: direct surface runoff and ground-water runoff (Figure 23). Such separation enabled estimates of the proportion of monthly surface- to ground-water runoff shown in Table 15, and lent an added dimension to understanding the inter-relationship between surface and ground water. There are many techniques of separation of these two components in a hydrograph (Kunkle, 1962; Riggs, 1963; Webber, 1961; Linsley *et al.*, 1958), but none offer a satisfactory, workable solution to all the complex interactions among geology, basin topography, precipitation, and in some cases, streamflow regulation. The method used presently (Riggs, 1963) assumes that the base-flow recession curve is described by the equation:

$$q_1 = q_0 K_r^{\Delta t}$$

where q_0 = flows at any time
q_1 = flow one time unit later
K_r = recession constant
Δt = one time unit

K_r is a measure of the rate of base-flow recession, and as it approaches unity, the rate approaches zero.

The equation for base-flow recession at the Baxter gauge was estimated to be:

$$\log \Delta q = \log (0.987) \Delta t$$

where $\Delta q = (q_0 - q_1)$

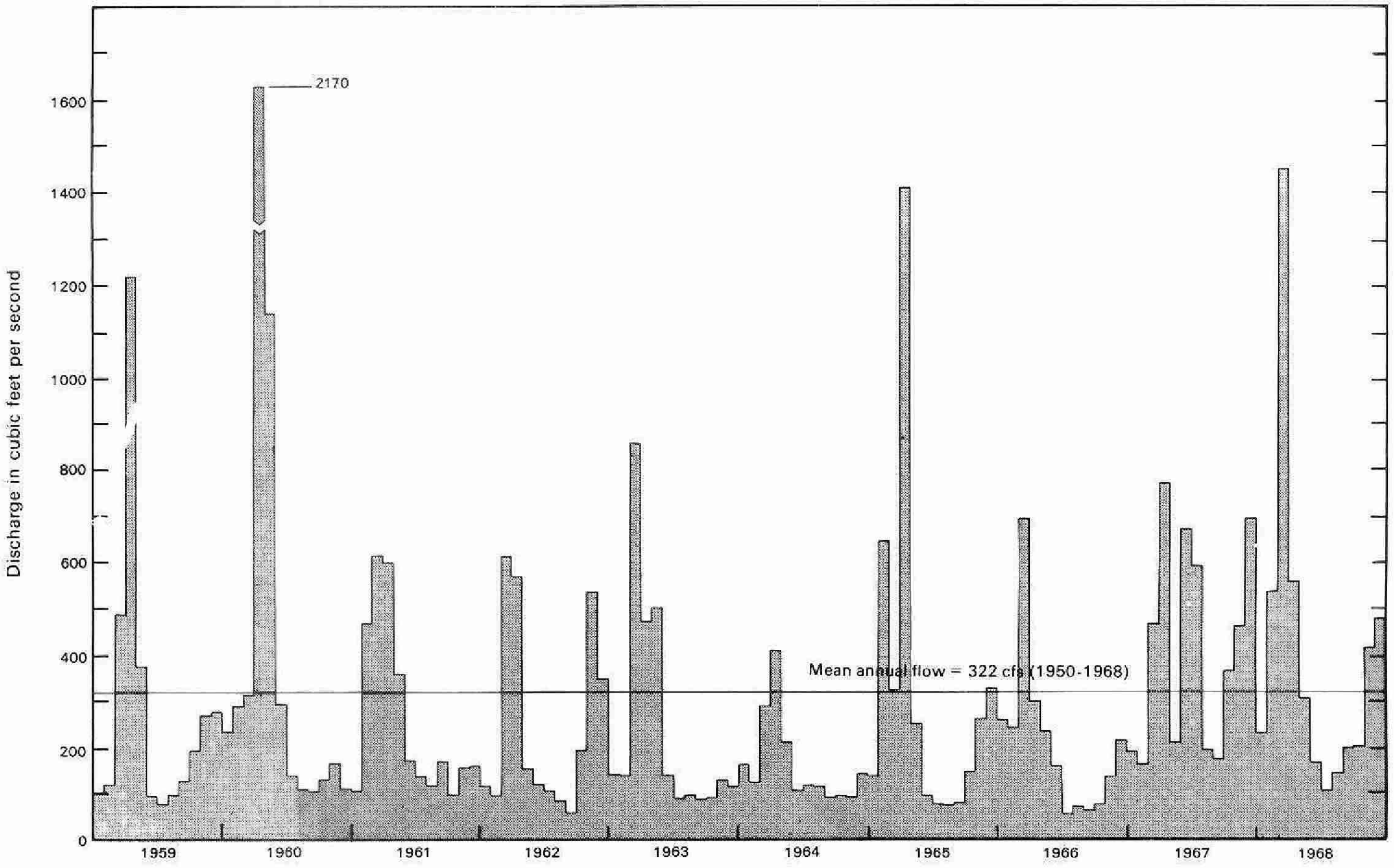


Figure 21. Monthly streamflow hydrograph, Nottawasaga River near Baxter, for the period 1959 to 1968.

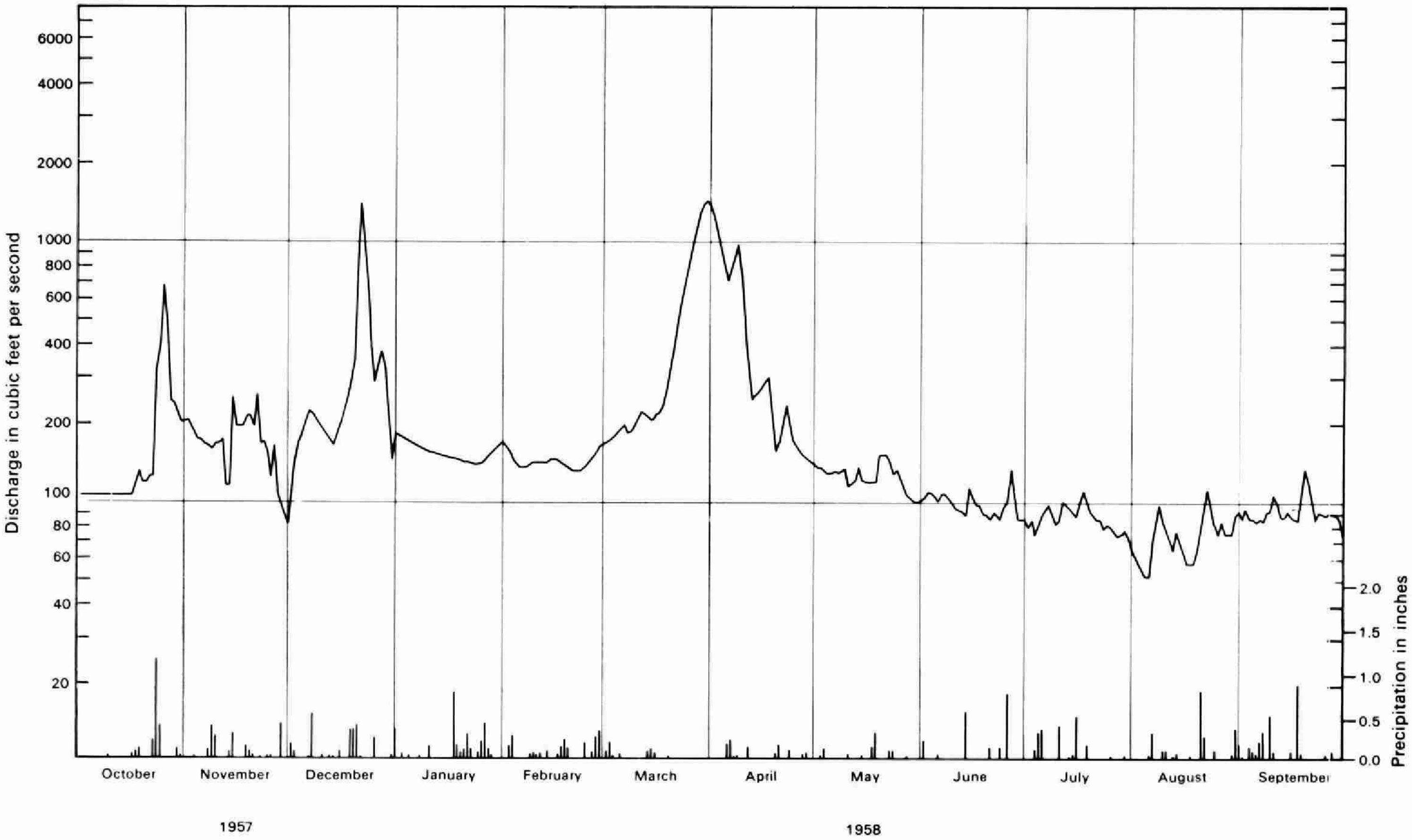


Figure 22. Basin precipitation and streamflow hydrograph for Nottawasaga River near Baxter, for the water year ending September 1958. *(below normal precipitation)*

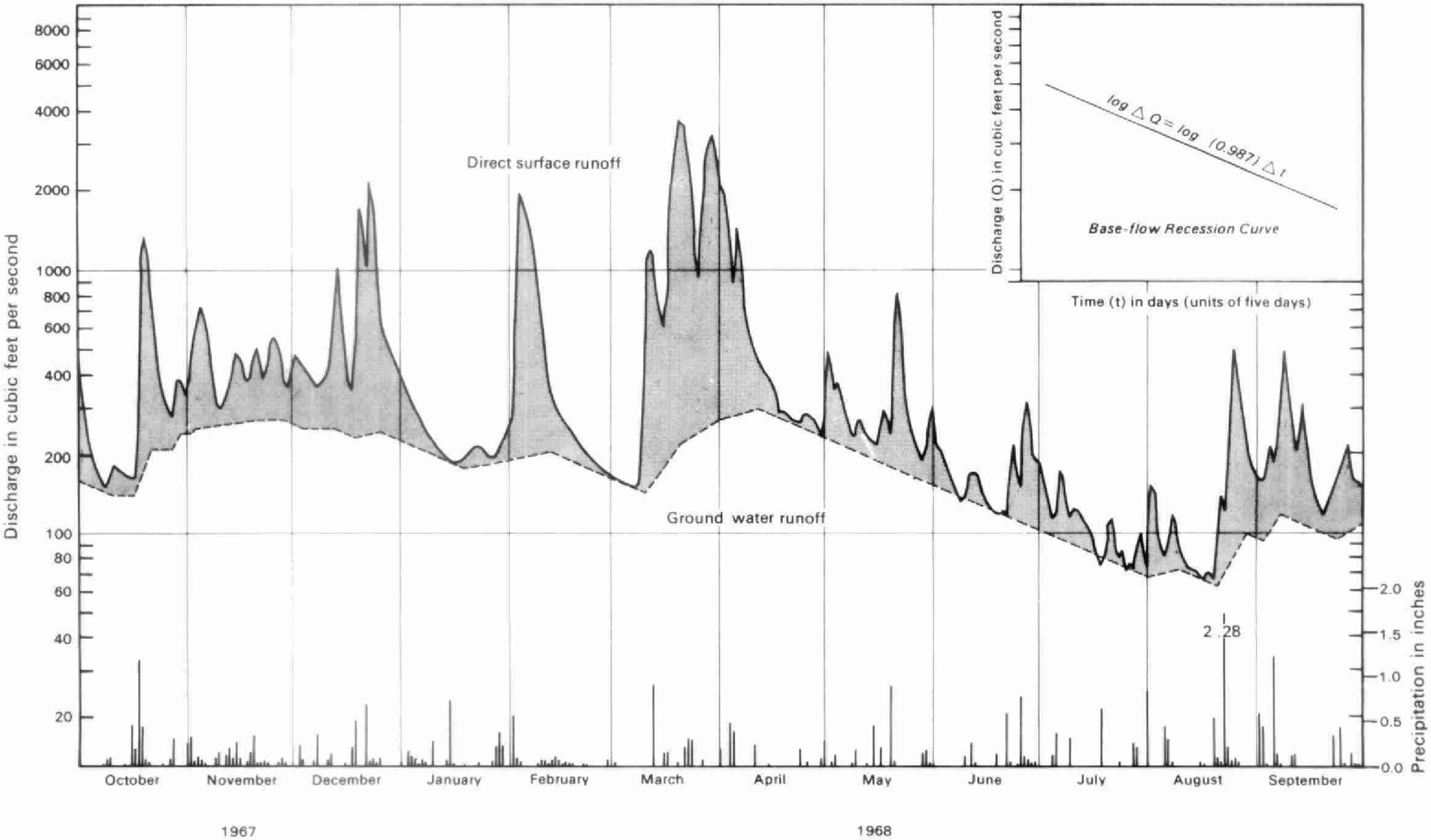


Figure 23. **Basin precipitation and streamflow hydrographs, showing components of streamflow in the Nottawasaga River near Baxter, for the water year ending September, 1968** ***(normal precipitation)*****.**

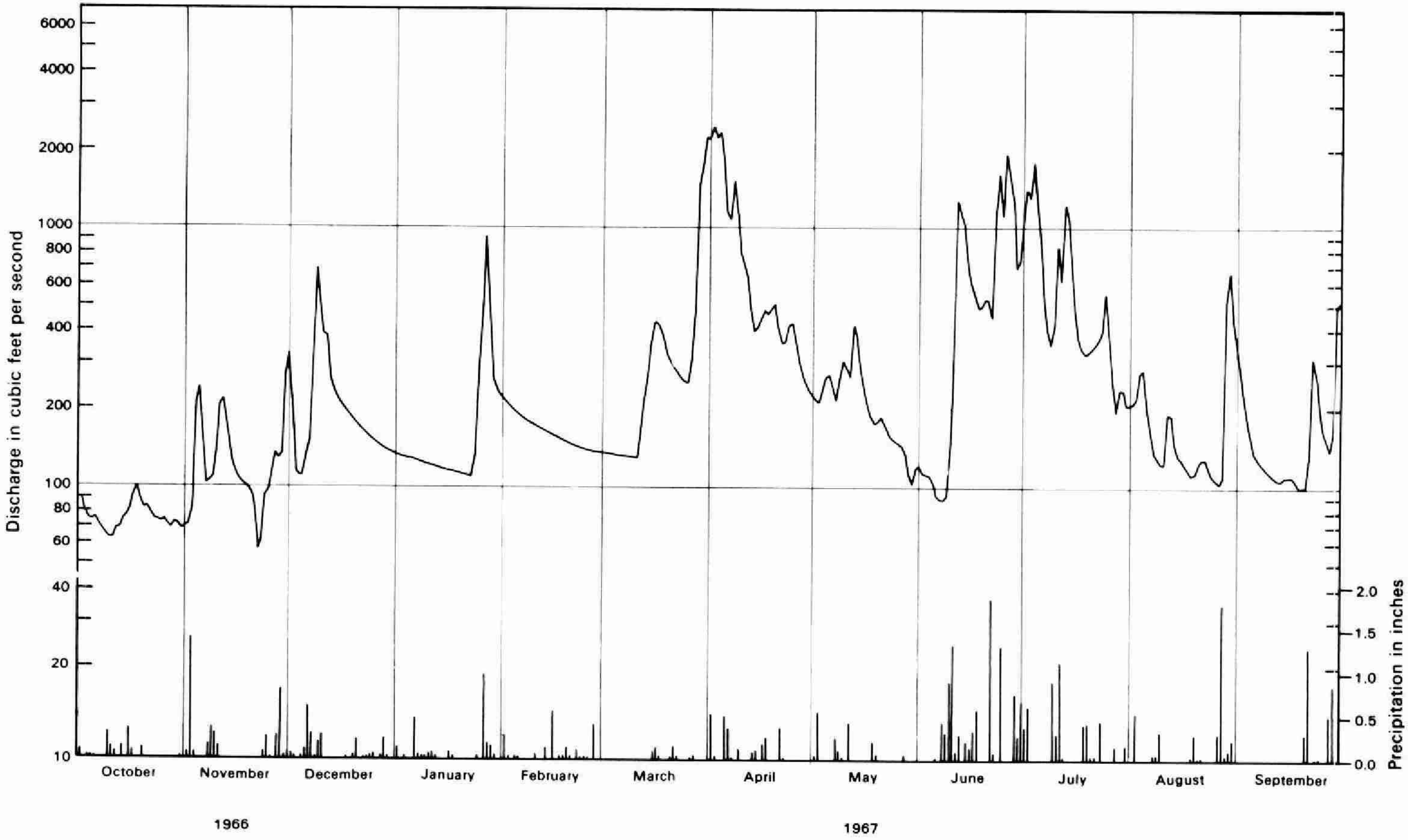


Figure 25. Basin precipitation and streamflow hydrograph for Nottawasaga River near Baxter, for the water year ending September 1967. *(above normal precipitation)*

The ground-water component of streamflow during the water year varied from an estimated low of 13 per cent in March (Table 15), when snowmelt produced large surface runoff, to a high of 84 per cent in January, when much of the precipitation was in the form of snow and very little direct surface runoff occurred. Streamflow during the summer months usually contains a larger proportion of ground-water discharge than during the winter.

Low- and High-Flow Frequencies

Flow frequency curves provide statistical data on flows during selected periods of consecutive days in the year. For design and planning of streamflow development, these curves complement the estimates obtained from flow-duration analyses.

Low-flow frequency curves were prepared for two streamflow recording stations on the Nottawasaga River near Baxter and on Bailey Creek near Beeton. The curves for the Nottawasaga River were based on 21 years of records (1948 to 1968).However, only six years of streamflow data for Bailey Creek were available (1963-1968). To calculate the low-flow frequency curves for this stream, the data were adjusted to cover the period 1948 to 1968 by following the method of adjustment outlined by Searcy (1960). The Baxter gauge was used as the index station. Low-flow frequency curves shown in figures 26 and 28 represent periods of 1 day, and 7, 15, and 30 consecutive days.

Lowest annual flows usually occur during the latter half of the summer and coincide with the period of stream-water withdrawals for irrigation. The reductions in streamflow due to these withdrawals are shown by the scatter of points about the lower ends of the low-flow frequency curves in Figure 26. The slightly steeper slope of the one-day curve may also reflect the greater sensitivity of the one-day low flows to stream-water withdrawals. The lowest recorded flows for 1 day, and 7, 15, and 30 consecutive days are 31, 42, 46, and 53 cfs rerespectively.

There are no reports of damages in the basin due to high flows, which occur most frequently in spring, although sections of the basin do become inundated, e.g., areas around Innisfil, Beeton, and Bailey creeks. The high-flow frequency curve is presented to complement the flow-duration curve in predicting future high flows (Figure 27). High-flow analysis is limited to flows for the Nottawasaga River near Baxter.

Local Low-Flow Analysis

Streamflows were measured during low-flow periods to provide preliminary estimates of low-flow yields from selected portions of the streams, and to calculate seven-day minimum flows for the larger ungauged streams. The data for these analyses consisted of continuous streamflow records for the Nottawasaga River near Baxter and Bailey Creek near Beeton, and of periodic streamflow measurements at selected sites (Map 2743B-2) during May to September 1968. For each of the periodically measured stations, an average low flow was calculated by averaging the three lowest flows measured during the summer. The results are listed in Table 8. The estimated annual seven-day low streamflows, for an average return period of 10 years (T=10), are shown in Figure 24 (in pocket).

The synthesis of seven-day low flows was based on the assumption that the annual seven-day low flow was proportional to the arithmetic mean of the lowest seven streamflow measurements made in the field. The Nottawasaga River near Baxter and Bailey Creek near Beeton were used as index stations.

Except for sections of the main stem of the Nottawasaga River itself, all the streams in the basin have annual seven-day low flows of less than 10 cfs (Figure 24). The headwaters of these streams have low flows of less than one cfs, and many have intermittent flows. In the Hockley Valley the low flow in the Nottawasaga River increases rapidly from less than 3 cfs at Glen Cross, to more than 10 cfs as it flows through Hockley. Once on the central sand plain, the seven-day flow in the river is greater than 20 cfs throughout the rest of the basin.

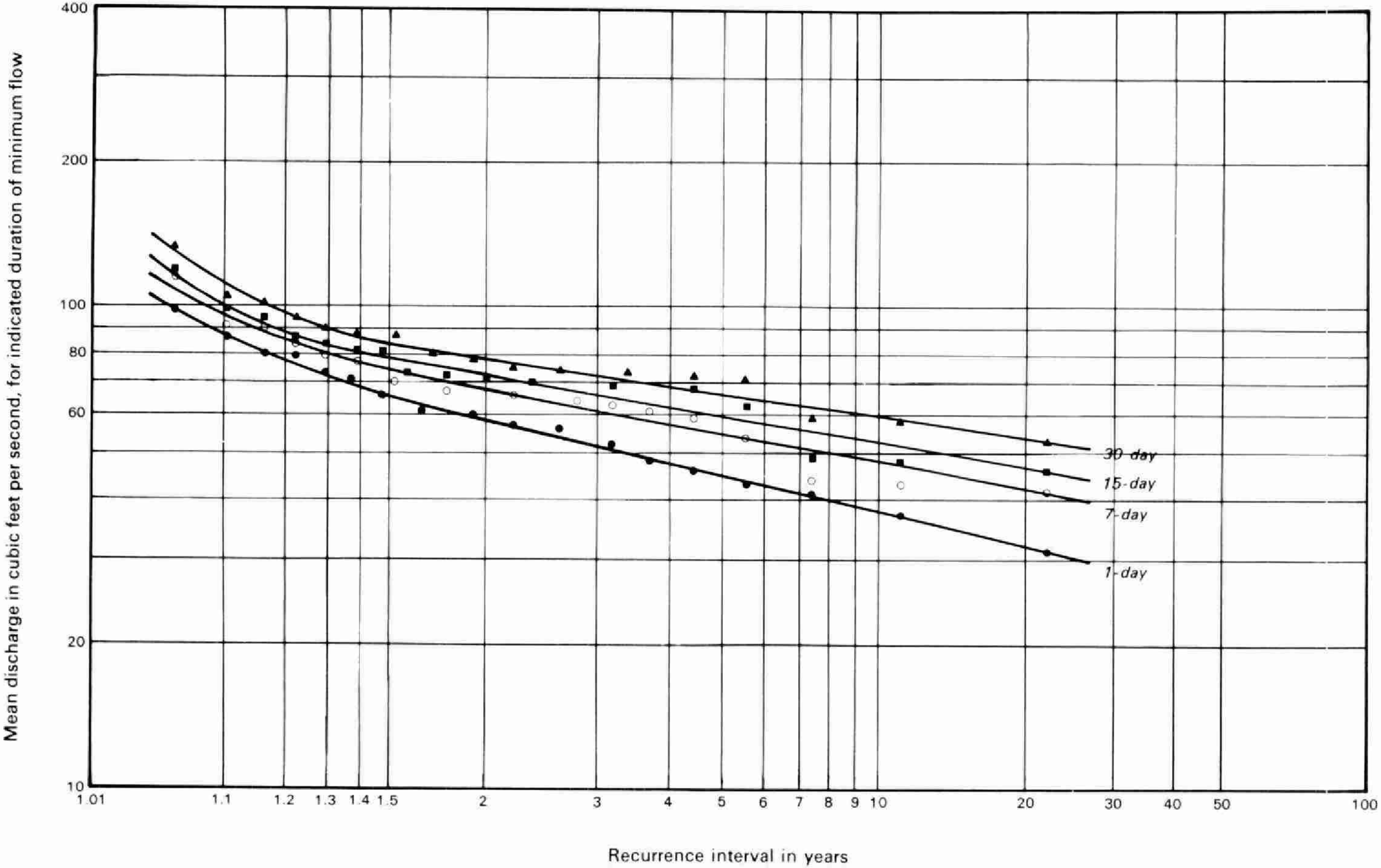


Figure 26. Annual low-flow frequency curves, Nottawasaga River near Baxter, based on 21 years of record (1948-1968).

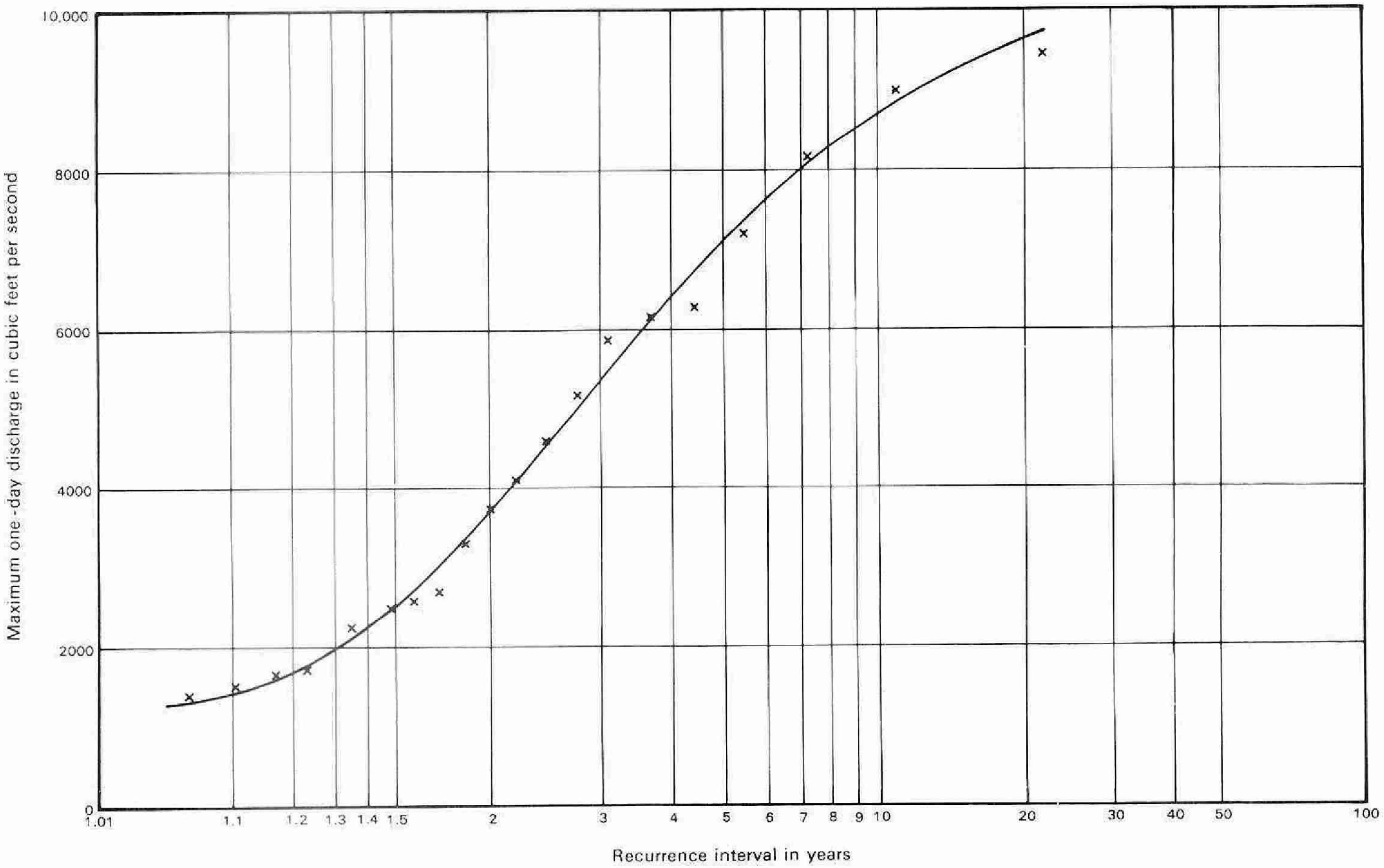


Figure 27. Annual high-flow frequency curve, Nottawasaga River near Baxter, based on 21 years of record (1948-1968).

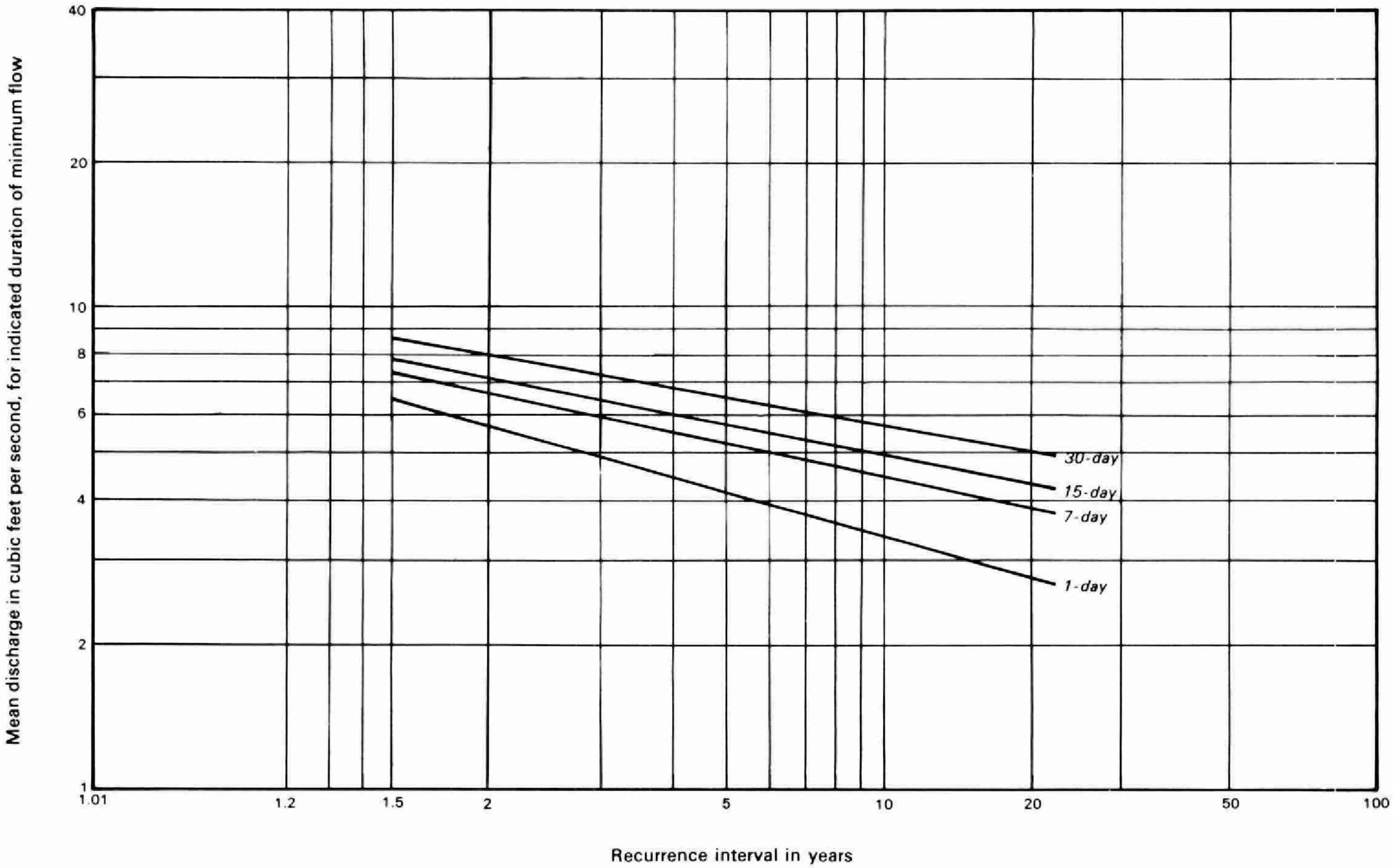


Figure 28. Synthesized annual low-flow frequency curves, Bailey Creek near Beeton.

Low-flow yields allow comparison of perennial yields from various areas of the watershed. It is inferred that most of the streamflow consisted of ground water at the time of measurement, and consequently the low flows represent discharge from ground-water storage. This explains the high value of 0.60 cfs per square mile in the Sheldon Creek drainage area, which is primarily in the Kame Hills physiographic region. Streamflows in areas in and above the Kame Hills physiographic region are considerably higher than in the rest of the basin, and ranged from 0.09 cfs to 0.60 cfs per square mile (Table 8). In fact, the best yields occurred in areas immediately below the escarpment, and are attributed to ground-water seepage from the face of the escarpment as well as from the kame gravels below it. Streamflow in the Ground Moraine and Sand Plain regions ranged from 0 to 0.16 cfs per square mile, except for the high values at stations 10 and 2ED-4. The high yield for station 10 might be attributed to streamflow regulation at the dam in Earl Rowe Park, as well as effluent discharges from Alliston. The apparent high yield above station 2ED-4 was calculated from flows based on 24-hour periods instead of instantaneous flow measurements, and this suggests that some of the yields calculated from instantaneous measurements in this area may be too low.

A decrease in streamflow between gauging stations 28 (2ED-100) and 27 on Beeton Creek is attributed to water storage in the reservoir at Tottenham. The decrease between stations 26 and 24 on Bailey Creek was probably due to withdrawal of water for irrigation.

Flow Duration

A flow-duration curve may at times be a valuable tool for assessing water resources in a drainage basin. Based on analysis of slopes in different parts of the curve, evaluations can be made of the variability of runoff, and the effects of such parameters as hydrology, geology, streamflow regulation, and water use on streamflow. A more comprehensive discussion of the versatility of this curve is given by Searcy (1959).

The flow-duration curve of streamflow at the Baxter gauge on the Nottawasaga River was based on 19 years of record (Figure 29). Due to the short period of records at all other stations in the basin, the long-term data at Baxter were deemed to be most reliable for this analysis.

The curve represents the integrated effects of hydrology and geology throughout the basin on streamflow. The relatively flat slope of the lower end of the curve suggests a perennial yield from ground-water storage. This yield (as base flow) can probably be attributed to ground-water discharge from the vast areas of permeable kame and sand deposits shown on Map 2743B-4. The slope throughout the rest of the curve is fairly uniform, even towards the upper end. This implies generally even rates of runoff through the year with no prolonged periods of high, "flash" discharges. Streamflow regulation and withdrawal have no marked effect on the curve during low flows.

Precipitation-Runoff Correlation

As stated earlier, streamflow consists essentially of water derived from two sources—from ground-water storage and from precipitation that forms direct surface-water runoff.

The correlation of precipitation to direct surface runoff can be expected to be fairly easily recognized, but correlation of precipitation to base flow is infinitely more complex. However, in spite of the complex relationship thought to exist because of the relatively large proportion of ground water in streams in the basin (Figure 23), four correlations of annual precipitation to total runoff from the basin are presented and evaluated.

Annual precipitation in the basin was calculated from data recorded at seven stations (see Table 10) in the vicinity of the basin, and total runoff out of the basin was indicated by streamflow at the Baxter gauge. Ten years of records (1952 to 1961) were used in the four correlations shown in Table 9.

Table 8. Comparison of Low-Flow Yields at Periodic Gauging Stations, Upper Nottawasaga River Basin (1968)

Station Number‡	Stream	Area Drained (sq. mi.)		Low Flow (cfs)		Yield (cfs/sq. mi.)	
		Gross* (A)	Nett† (a)	Gross*(Q)	Nett†(q)	Q/A	q/a
2ED-3	Nottawasaga River	469		73.4		0.16	
2	Nottawasaga River	316		54.8		0.17	
4	Nottawasaga River	66.1	20.1	20.7	11.3	0.31	0.56
5	Nottawasaga River	20.6	20.6	5.3	5.3	0.26	0.26
6	Tributary of Nottawasaga R.	16.0	16.0	2.4	2.4	0.15	0.15
7	Tributary of Nottawasaga R.	6.9	6.9	1.0	1.0	0.14	0.14
8	Tributary of Nottawasaga R.	10.8	10.8	1.0	1.0	0.09	0.09
9	Tributary of Nottawasaga R.	5.3	5.3	0.2	0.2	0.04	0.04
29	Sheldon Creek	32.8	16.2	12.6	2.7	0.38	0.17
30	Sheldon Creek	16.6	16.6	9.9	9.9	0.60	0.60
33	Tributary of Nottawasaga R.	25.4	25.4	4.1	4.1	0.16	0.16
18	Innisfil Creek	183	25.1	13.9	0.4	0.08	0.02
19	Innisfil Creek	38.9	14.4	2.4	1.3	0.06	0.09
20	Innisfil Creek	24.5	24.5	1.1	1.1	0.04	0.04
21	Penville Creek	23.0	23.0	0.3	0.3	0.01	0.01
22	Cookstown Creek	14.0	14.0	0.4	0.4	0.03	0.03
24	Bailey Creek	40.6	19.4	2.4	-1.5	0.06	-0.08
25	Keenansville Creek	21.2	16.2	3.9	2.3	0.18	0.14
26	Bailey Creek	5.0	5.0	1.6	1.6	0.32	0.32
27	Beeton Creek	34.6	6.2	3.1	-0.6	0.10	-0.10
28	Beeton Creek	28.4	28.4	3.7	3.7	0.13	0.13
2ED-4	Bailey Creek	82.2	7.0	10.4	4.9	0.13	0.70
10	Boyne River	84.7	5.2	17.1	4.1	0.20	0.79
12	Boyne River	61.4	15.2	11.3	1.4	0.18	0.09
13	Boyne River	46.2	12.7	9.9	5.9	0.21	0.46
14	Boyne River	33.5	33.5	4.0	4.0	0.12	0.12
16	Tributary of Boyne River	9.1	9.1	<0.1	<0.1	0.00	0.00
17	Tributary of Boyne River	9.0	9.0	1.6	1.6	0.18	0.18

* Gross area or discharge refers to the total at the station.

† Net area or discharge refers to the portion between the indicated station and the next station upstream.

‡ Location shown on Map 2743B-2.

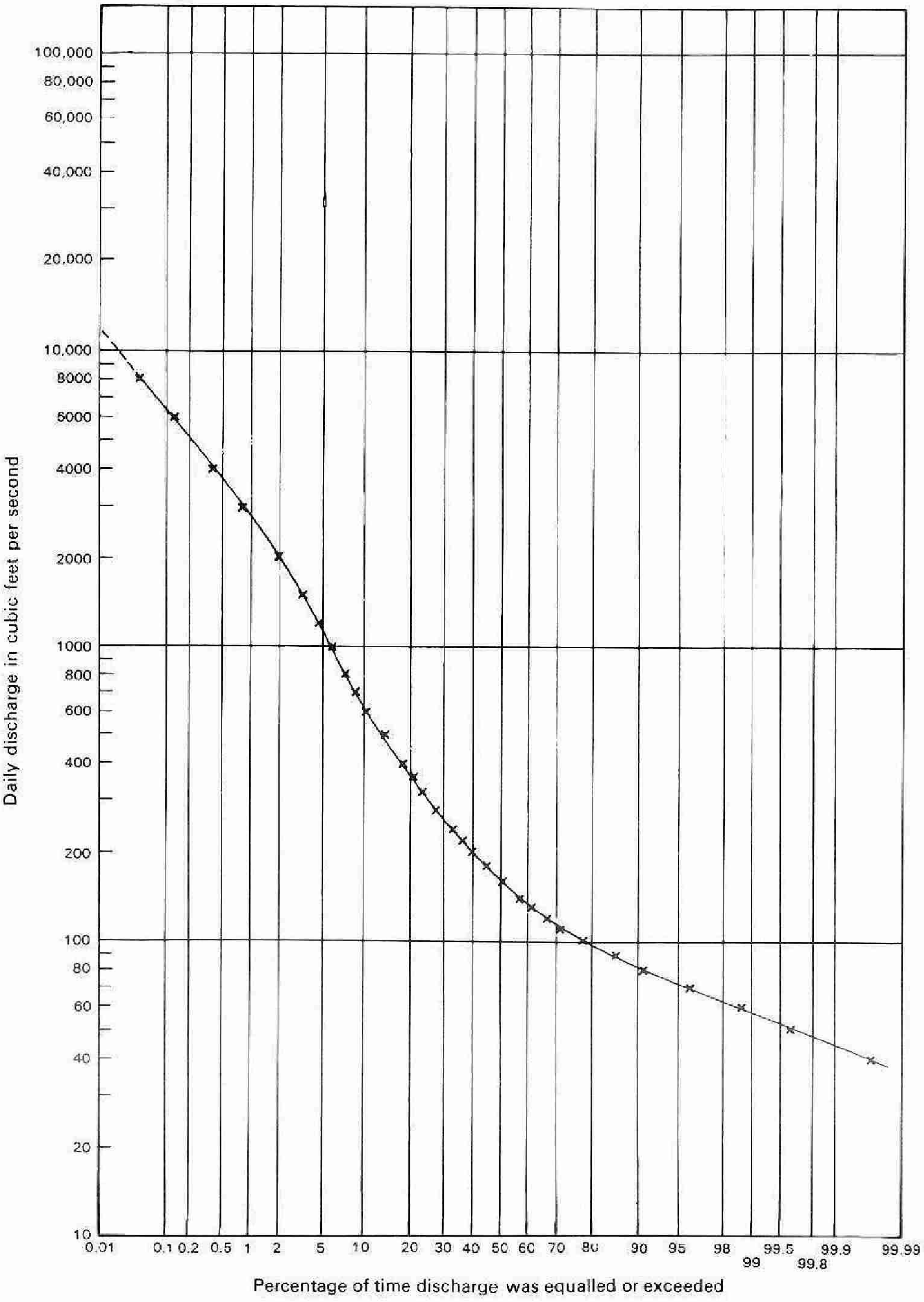


Figure 29. Duration curve of daily flows, Nottawasaga River near Baxter, based on 19 years of record (1950-1968).

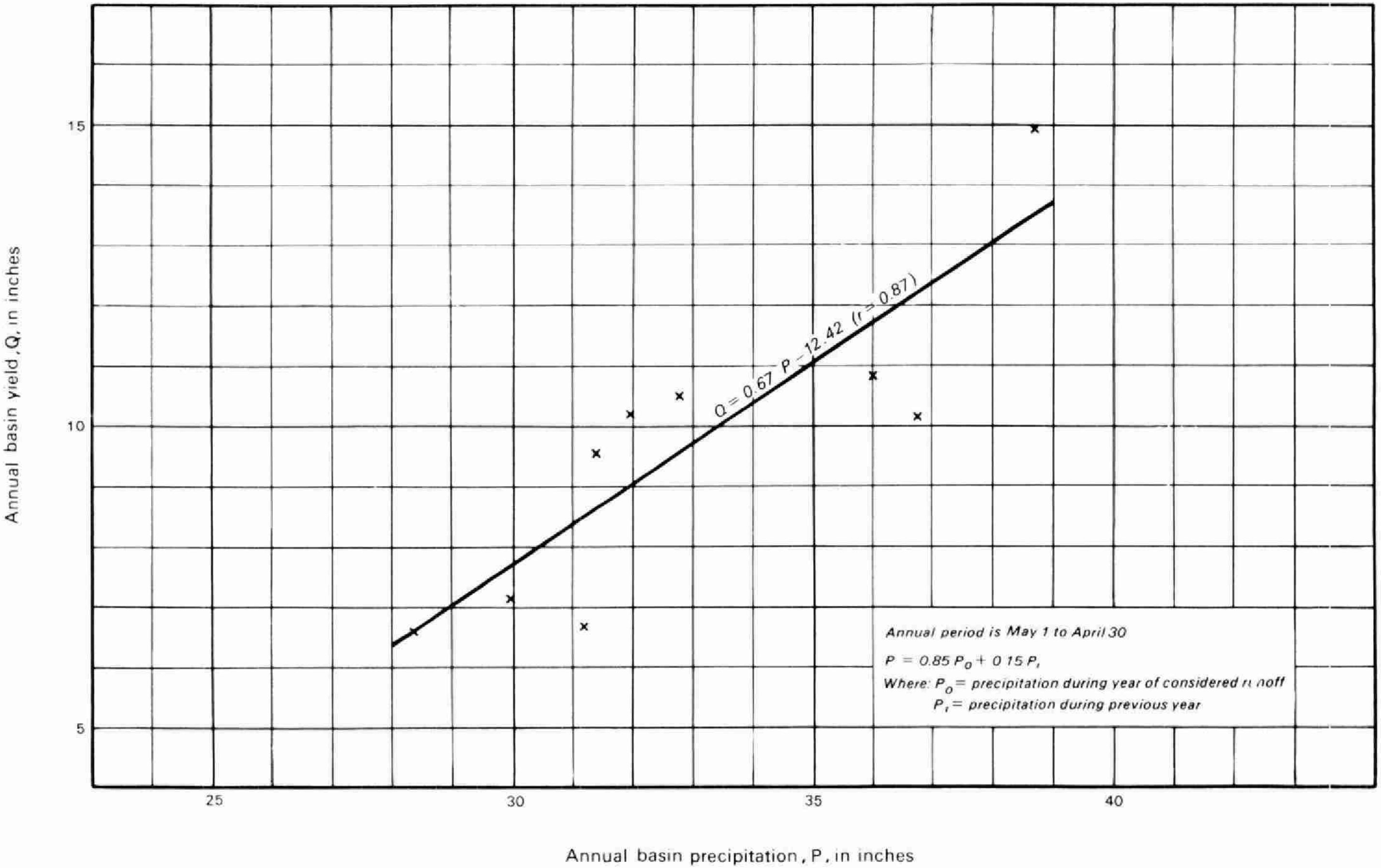


Figure 30. Correlation between basin yield and precipitation, Upper Nottawasaga River basin, based on nine years of record (May 1, 1952 to April 30, 1961).

Table 9. Four Methods of Linear Correlation of Annual Basin Precipitation with Annual Streamflow in the Nottawasaga River near Baxter, for the Years 1952 to 1961 Inclusive

(All values in inches)

Year Ending	Case a		Case b		Case c		Case d	
	P_a	Q_a	P_b	Q_b	P_c	Q_c	P_d	Q_d
1952	34.20	10.45						
1953	34.40	7.68	34.30	7.68	30.87	6.64	31.18	6.64
1954	36.83	9.94	35.62	9.94	37.83	10.17	36.79	10.17
1955	33.20	15.00	35.02	15.00	39.00	14.94	38.82	14.94
1956	39.80	13.40	36.50	13.40	31.72	10.52	32.81	10.52
1957	29.79	8.75	34.80	8.75	32.04	10.17	31.99	10.17
1958	23.16	5.86	26.48	5.86	29.58	7.07	29.95	7.07
1959	36.35	7.50	29.76	7.75	28.15	6.56	28.37	6.56
1960	33.37	13.70	34.86	13.70	37.46	10.83	36.06	10.83
1961	32.30	7.74	32.84	7.74	30.34	9.56	31.41	9.56
	Year: Oct 1 to Sept 30 $P_a = P_o$ $Q_a = 0.33\ P_a - 1.07$ $r = 0.48$		Year: Oct 1 to Sept 30 $P_b = \frac{1}{2}(P_o + P_1)$ $Q_b = 0.70\ P_b - 13.25$ $r = 0.69$		Year: May 1 to Apr 30 $P_c = P_o$ $Q_c = 0.53\ P_c - 7.93$ $r = 0.81$		Year: May 1 to Apr 30 $P_d = 0.85\ P_o + 0.15\ P_1$ $Q_d = 0.67\ P_d - 12.42$ $r = 0.87$	

$P_a \ldots P_d$ = "effective" precipitation in the basin, made up of P_o and P_1.
P_o = annual precipitation in the basin for current year.
P_1 = annual precipitation in the basin for the antecedent year.
$Q_a \ldots Q_d$ = annual discharge from the basin (basin yield).
r = coefficient of correlation.

Case a tests a linear relation between annual precipitation and runoff, and case b correlates current and antecedent precipitation to runoff. In case c, the "annual" time period is changed from a standard water year (October 1 to September 30) to the period May 1 to April 30, as used by Sharpe *et al.* (1960). Case d correlates current and antecedent precipitation over the interval May 1 to April 30, to runoff during this period.

The relationship established in case a is poor as the coefficient of correlation r is 0.48. Better correlations were obtained in cases b and c, and case d produced the best results (r=0.87). The equation of the regression line in case d is:

$$Q = 0.67\,(0.85\ P_o + 0.15\ P_1) - 12.42$$

where Q = annual runoff from basin (inches)
P_o = annual precipitation in the basin for the current year (inches)
P_1 = annual precipitation in the basin for the antecedent year (inches)

The above equation, in the form of the regression line shown in Figure 30, may be used to estimate the annual discharge out of the basin if precipitation is known, or conversely to calculate an approximate basin precipitation on the basis of streamflow at Baxter. In either case, however, the results must be regarded only as approximations because there is a considerable scatter of points about the line which was fitted by the least-squares method.

Precipitation

Precipitation recharges surface- and ground-water storage, and as such, its frequency of occurrence, amount, and areal distribution determine the availability of water in streams, lakes, and sub-surface formations.

Discussions of precipitation in this section include an evaluation of its amount and frequency of occurrence at the Beeton meteorological station, and an estimate of total precipitation in the basin for the 1968 water year.

For the purpose of calculating the hydrologic budget, average precipitation in the basin was estimated on the basis of data from seven stations in the area (Table 10), but for purposes of general discussions, precipitation data at the Beeton station are used to indicate the magnitude of seasonal and annual variations of rain and snow in the basin. Total precipitation on the Escarpment Upland physiographic region is usually higher than to the east, but since the upland area in the basin is relatively small, precipitation characteristics at the higher elevations are not described.

Table 10. The Period of Precipitation Records at Meteorologic Stations in the Vicinity of the Upper Nottawasaga River Basin (modified from Potter, 1966)

Station Name	Period of Record With No Change in Program, Location, or Name
Albion	May 1956 to present*
Alliston	Mar 1953 to Nov 1960
	Oct 1967 to present
Beeton	Nov 1916 to present
Borden A	Sept 1966 to present
Essa	Aug 1958 to present
Orangeville	Apr 1883 to May 1912
	Jul 1949 to present
Redickville	Oct 1944 to present

*"present" in this table is Jan 1969.

Average precipitation in the basin during the 1968 water year was estimated to be 33.19 inches, which is 2.36 inches more than the 30-year (1930-1960) normal precipitation at Beeton.

Precipitation at Beeton

Precipitation data at the Beeton meteorological station have been gathered since 1917, and analyses of precipitation characteristics are based on 49 years of complete daily records (1917 to 1961, and 1964 to 1967). General characteristics of monthly precipitation are shown in Table 11. More specifically, Figure 31 shows the variation of annual precipitation during the period 1917 to 1967. Within this interval, the maximum annual precipitation of 45.40 inches occurred in 1954, and the minimum of 21.51 inches in 1946. The long-term 49-year average annual precipitation of 29.43 inches in 1.40 inches less than the 30-year (1931-1960) "normal" precipitation reported by the Canada Department of Transport (1965).

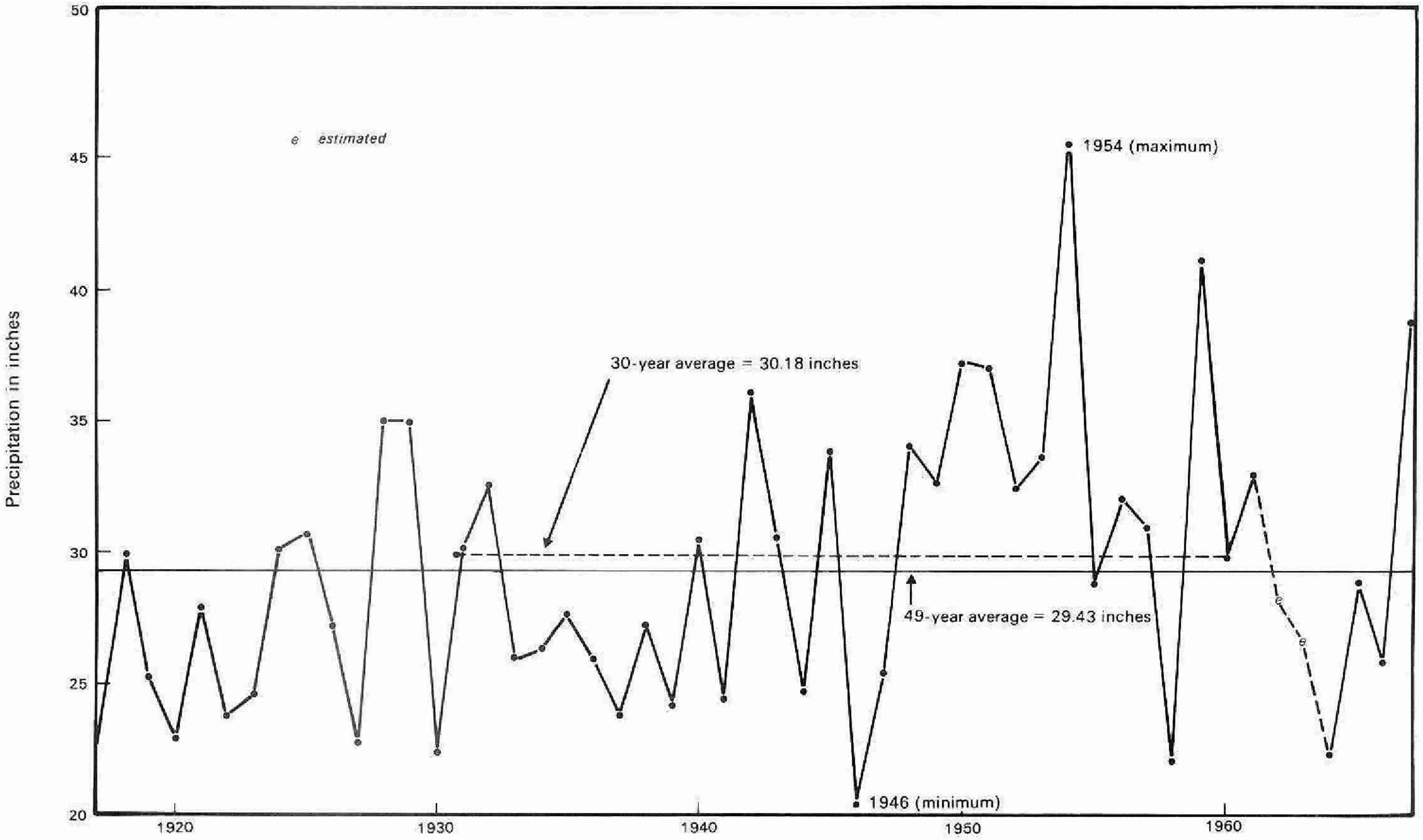


Figure 31. **Annual precipitation, Beeton meteorologic station,for the period 1917 to 1967.**

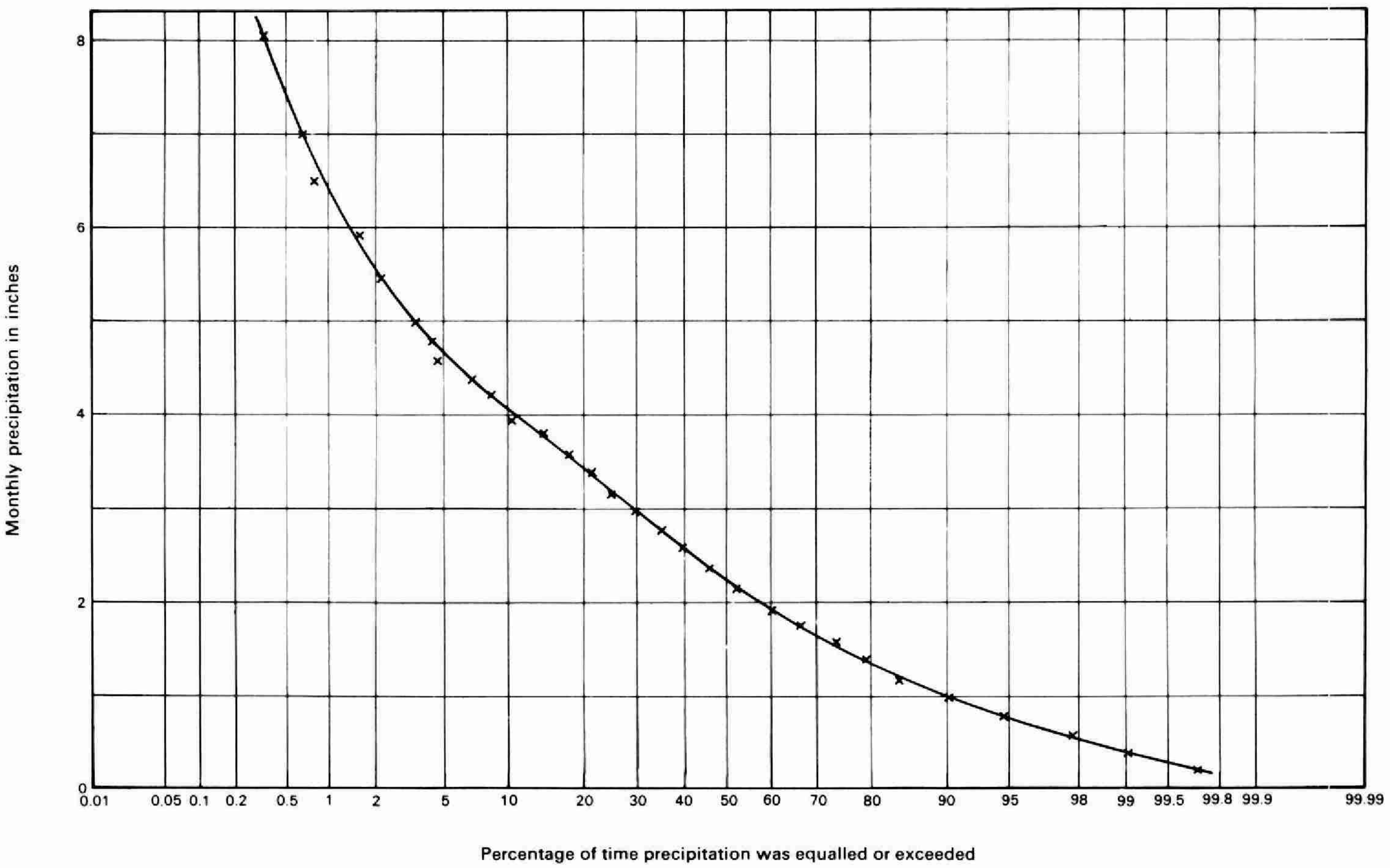


Figure 32. Duration curve of monthly precipitation, Beeton meteorologic station, based on 51 years of record (1917 - 1967).

Table 11. Characteristics of Precipitation at the Beeton Meteorologic Station, Based on Data from 1917 to 1961 and from 1964 to 1967

(All precipitation values in inches)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Average monthly precipitation	2.18	2.03	2.36	2.53	2.70	2.68	2.97	2.78	2.58	2.23	2.32	2.07
Average number of days of precipitation during the month	10	8	9	9	9	8	8	7	8	8	9	10
Minimum monthly precipitation on record	0.58	0.31	0.35	0.58	0.47	0.53	0.59	0.11	0.24	0.10	0.25	0.60
Number of times when the minimum monthly precipitation was also the annual minimum	5	5	3	2	3	4	4	1	4	6	2	6
Maximum monthly precipitation on record	4.55	4.18	5.77	5.64	7.00	11.28	7.10	6.47	5.13	8.27	6.52	4.46
Number of times when the maximum monthly precipitation was also the annual maximum	1	1	2	3	8	2	8	5	7	4	2	2

49-year average annual total =29.43 inches
Maximum annual total on record=45.40 inches (in 1954)
Minimum annual total on record=21.51 inches (in 1946)

The duration curve shown in Figure 32 presents a statistical analysis of time variation of precipitation at the station. The curve may be used to associate a frequency of occurrence with the monthly precipitation amounts shown in Table 11. For example, the average January total of 2.18 inches was equalled or exceeded about 53 per cent of the time, and the minimum monthly total on record during January (0.58 inches) was equalled or exceeded about 97 per cent of the time. Fifty per cent of the time the monthly precipitation equalled or exceeded approximately 2.5 inches, and 99 per cent of the time the monthly total was equal to or greater than about 0.4 inches (the average of the 49-year monthly minima). Only 1 per cent of the time did the monthly precipitation equal or exceed about 6.4 inches (the average of the 49-year monthly maxima).

Evapotranspiration

Evapotranspiration (ET) represents a loss of water over which man has little control but which is essential for plant life. As a process in the hydrologic cycle, it is responsible for water losses in the order of 70 per cent from the upper Nottawasaga River drainage basin.

Table 12. Calculation of Potential and Actual Evapotranspiration by the Thornthwaite Method for the 1968 Water Year

(Meteorologic data from Beeton station)

Determination	1967			1968									Total
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	
1. Air Temperature (°F).	47.1	32.8	26.9	14.0	15.6	31.9	45.7	50.5	62.8	67.8	65.2	61.8	
2. Heat index	2.52	0.40	0	0	0	0	1.30	3.81	6.84	8.47	7.91	5.49	36.74
3. Correction factor	0.95	0.80	0.76	0.81	0.82	1.02	1.13	1.27	1.29	1.30	1.20	1.04	
4. Potential Evapotranspiration (inches)	1.42	0	0	0	0	0	1.54	2.35	4.27	5.02	4.30	3.31	22.21
5. Precipitation (inches)	3.40	2.64	2.84	2.63	1.41	2.83	1.84	2.51	2.27	2.84	4.26	3.72	33.19
6. Precipitation minus Potential Evapotranspiration (inches)	1.98	2.64	2.84	2.63	1.41	2.83	0.30	0.16	-2.00	-2.18	-0.04	0.41	10.98
7. Continuous sum of negative values of 6 (inches)									-2.00	-4.18	-4.22		
8. Total Storage (inches)	10.89	11.81	14.65	17.28	18.69	11.81	11.81	11.81	10.24	8.54	8.50	8.91	
9. Change in soil moisture (inches)	1.98	0.92	0	0	0	0	0	0	-1.57	-1.70	-0.04	0.41	
10. Actual Evapotranspiration (inches)	1.42	0	0	0	0	0	1.54	2.35	3.84	4.53	4.30	3.31	21.29

Estimates of ET in this report are made to complement the water budget for the 1968 water year, and at the same time to compare estimates of ET by three different methods:

1) the Thornthwaite method,
2) the procedure developed by Konstantinov,
3) the water-balance method.

Although each of the methods contains inherent errors due to assumptions that are often unrealistic and difficult to duplicate in the field, a consistency in the results obtained by the three methods (Table 15) indicates that the estimates of evapotranspiration are acceptable for purposes of the present report.

Thornthwaite (1948) proposed a method of calculating evapotranspiration based on estimates of "potential" evapotranspiration (PE) and precipitation as shown in Table 12. The monthly average temperature and monthly precipitation required by this method were obtained from the Beeton meteorologic station. The soil moisture storage capacity was assumed to be 11.81 inches. Potential evapotranspiration during the 1968 water year was calculated to be 22.21 inches, and the ET was 21.29 inches.

One obvious shortcoming of the Thornthwaite procedure is reflected in the basic assumption that PE and ET depend only on temperature, and that evaporation does not take place during months when the mean monthly air temperature is below 0°C. Consequently, the annual estimate of PE and ET by this method are expected to be lower than the values calculated by methods that consider the additional factors of vapour pressure, wind, and solar radiation.

Kienitz, *et al.* (1968) describe a method of ET calculation developed by Konstantinov, which utilizes air temperature and vapour pressure data. Vapour pressures were obtained from relative humidity data at the Borden A climatalogical station. By this method, the loss of water due to ET during the 1968 water year amounted to 22.95 inches (Table 13), which exceeds that calculated by the Thornthwaite method by approximately eight per cent. The differences in monthly values are considerably greater in some cases.

Table 13. Calculation of Evapotranspiration by the Konstantinov Method for the 1968 Water Year

(Meteorologic data from Borden A station)

Month	Air Temperature (°C)	Vapour Pressure (mb)	Evapotranspiration (inches)
Oct 1967	8.4	8.7	1.22
Nov	0.4	5.1	0.26
Dec	-2.6	4.1	0.11
Jan 1968	-9.8	2.4	0.22
Feb	-9.2	2.3	0.37
Mar	-0.4	4.7	1.46
Apr	7.4	6.5	2.07
May	9.9	8.6	3.42
June	16.9	14.1	3.90
July	20.2	15.6	3.66
Aug	18.4	15.6	3.78
Sept	16.1	14.4	2.48
Total			22.95

In the third method, the assumption is that in the long term, natural changes in storage of soil moisture, ground water, and surface water can be neglected from the hydrologic budget equation. This assumption, however, may not be valid for a one-year budget, but it was accepted for the 1968 water year because of insufficient data about these parameters in the basin. Consequently, the simplified water balance equation

$$ET = P - R$$

was used to estimate annual ET, which amounted to 20.45 inches.

A tabulated summary of evapotranspiration estimates by the three methods is shown in Table 14. The monthly values of ET obtained by the Konstantinov method are favoured, and are used in calculating the monthly and annual hydrologic budgets in the basin.

Table 14. Comparison of the Results of Evapotranspiration Calculations by the Water-Budget, Thornthwaite, and Konstantinov Methods for the 1968 Water Year

Month	Evapotranspiration (inches)		
	Water Budget	Thornthwaite	Konstantinov
Oct 1967		1.42	1.22
Nov		0.00	0.26
Dec		0.00	0.11
Jan 1968		0.00	0.22
Feb		0.00	0.37
Mar		0.00	1.46
Apr		1.54	2.07
May		2.35	3.42
Jun		3.84	3.90
Jul		4.53	3.66
Aug		4.30	3.78
Sept		3.31	2.48
Total	20.45	21.29	22.95

Hydrologic Budget

A hydrologic budget calculation in this report serves to summarize estimates of precipitation, runoff, and evapotranspiration, and to relate these parameters to each other by the budget equation:

$$P = R + ET + \Delta S$$

where P = precipitation
R = runoff
ET = evapotranspiration
ΔS = changes in surface water, ground water, and soil moisture storage

Using the ET estimates obtained by the Konstantinov method, estimates of monthly and annual budgets for the 1968 water year are presented in Table 15.

Table 15. Estimates of Monthly Hydrologic Budgets for the 1968 Water Year

(All values in inches, except as indicated)

Month	Precipitation	Runoff			Evapo-tran-spiration	Changes in Storage*
		Direct	Ground Water	Ground Water as % of Total Runoff		
Oct 1967	3.40	0.49	0.43	48	1.22	+1.26
Nov	2.64	0.47	0.62	57	0.26	+1.29
Dec.	2.84	1.10	0.60	35	0.11	+1.03
Jan 1968	2.63	0.09	0.47	84	0.22	+1.85
Feb	1.41	0.80	0.43	35	0.37	-0.19
Mar	2.83	3.13	0.48	13	1.46	-2.24
Apr	1.84	0.73	0.61	45	2.07	-1.57
May	2.51	0.34	0.42	55	3.42	-1.67
Jun	2.27	0.13	0.28	68	3.90	-2.04
Jul	2.84	0.08	0.19	72	3.66	-1.09
Aug	4.26	0.18	0.18	51	3.78	+0.12
Sept	3.72	0.24	0.25	51	2.48	+0.75
Total	33.19	7.78	4.96	39	22.95	-2.50

*Negative values indicate a loss from storage, positive a gain; storage occurs as ground water, soil moisture, and snow.

During this year, the calculated water loss from the basin exceeded recharge by almost eight per cent. This excess would require a decline in storage equivalent to 2.50 inches of water over the basin. However, this difference in the water balance may not be all a loss from storage because some of it could be due to errors in measurements or calculations of the other parameters in the equation, or may be attributed to differences in amounts of ground water flowing into and out of the basin. There are no significantly large lakes or ponds in the basin to store surface water during the summer months, and during this time storage changes can be attributed mainly to ground water and soil moisture. During the winter months, however, surface-water storage in the form of snow can be considerable, and changes in snowpack will be reflected in ΔS, while changes in soil moisture will likely be small. Such is the case during March when much of the 2.24 inches of loss of water from storage is due to the melting of snow. The snowmelt during this month produced close to 40 per cent of the total annual direct runoff from the basin, and the base flow of 13 per cent was the lowest for the year.

WATER QUALITY

Introduction

Water quality is an important consideration in management and development of surface- and ground-water resources. The purpose of this section is to describe the chemical quality of surface and ground waters in the basin, and to compare the existing quality with criteria primarily for domestic and irrigation uses.

Thirty ground-water samples, eight surface-water samples, and one rainwater sample were collected during July and August 1968, and the chemical analyses of these samples were carried out at the laboratories of the OWRC. The results are shown in Appendix B and the locations of the sampling stations are indicated on Map 2743B-6. The ground-water samples consisted of 9 samples from bedrock wells and 21 from wells of varying depths in overburden aquifers. All the stream samples were taken at streamflow gauging sites during the course of streamflow measurements. Three samples were collected from the Nottawasaga River and the rest from the major tributaries in the basin.

The chemical elements and ionic compounds are reported as their own ions, i.e., chloride as Cl^-, etc., except the following parameters: hardness and alkalinity are both reported as $CaCO_3$, and nitrate is reported as nitrogen. The total iron concentration consists of dissolved and undissolved iron in the sample. The concentrations of the various parameters are reported in parts per million (ppm), i.e., one part of salt, by weight, exists in one million parts of water, by weight. In some calculations, it has been more advantageous to use "equivalents per million" (epm) and standard conversion factors (Hem, 1959, p. 32) have been used to change from ppm to epm.

The general chemical quality of water in the basin is presented utilizing water quality diagrams and trilinear plots, and the suitability of surface and ground waters for domestic and irrigation uses is discussed.

General Classification of Waters

A classification of surface and ground waters is made to note the differences in chemistry among rainwater, surface-water, and ground-water samples, and to compare surface- and ground-water chemistry at various locations in the basin. The latter comparison serves as a means of assessing the degree of "metamorphism" of ground waters according to the anion sequence (Chebotarev, 1955):

$$HCO_3 \rightarrow SO_4 \rightarrow Cl$$

The classifications are based on the dominant concentrations of anions and cations in the trilinear diagrams shown in Figure 33 and in the chemical diagrams indicated on Map 2743B-6. The points on the trilinear plots represent ionic concentrations in per cent epm, and the figures on the map indicate ionic concentrations in epm.

Precipitation, although "pure" by most standards, is not completely devoid of mineral content. For example, the following list shows the concentration of some constituents in a rainwater sample collected at the Cookstown observation well:

Chemical Parameter	Concentration (ppm)
Hardness	24
Total Iron	0.15
Chloride	1
Sodium	0.6
Potassium	0.2
Magnesium	1
Calcium	9
Sulphate	4
Bicarbonate	21
Nitrate	0.04
Total Dissolved Solids	58

This rainwater sample is of "calcium bicarbonate" type. Calcium makes up 80 per cent of the cations and bicarbonate is 79 per cent of the epm anion concentration (Figure 33). Calcium and bicarbonate ions are also the predominant ions in all of the surface-water and in most of the ground-water samples. Sulphate ions do not predominate in any of the water samples; one sample, from well 949, contains 60 per cent chloride. Because this well, only 30 feet deep, is adjacent to Highway 11, pollution by road salts is suspected, and the sample is not indicative of natural ground-water chemistry.

The largest variations in ionic concentrations occur among cations in the ground-water samples. The variations are due primarily to base exchange between sodium and calcium, with exchange between sodium and magnesium being secondary. Sodium percentages vary from 2 to 84 per cent, calcium from 11 to 85 per cent, and magnesium from 4 to 47 per cent.

The chemical diagrams on Map 2743B-6 show basically the same predominance of calcium and bicarbonate as indicated by the trilinear plots. The shapes of most of the diagrams on the map are similar to that of rainwater. However, the ionic concentrations in the surface- and ground-water samples are much higher than in the rainwater sample. The total dissolved solids in stream water are smaller than in most of the ground-water samples, but there are no distinguishable differences between ground-water samples from bedrock and overburden wells.

As most waters in the basin are of bicarbonate type, there has not been significant metamorphism of the waters. Even the ground waters from deep formations beneath the central sand plain are relatively unchanged from this type.

Chemical Constituents and Characteristics

A discussion of water quality in terms of ionic concentrations and their distributions in surface and ground waters is essential in defining the quality characteristics of the resource. In the following descriptions, the concentrations of the major cations and anions are dealt with in terms of the possible source, the amount, and the distribution of the ions in surface and ground waters in the basin. The composition of one sample of rainwater has already been listed, and the samples of surface and ground water in the basin are grouped according to: 1) water in streams, 2) ground water in overburden, and 3) ground water in limestone and shale bedrock. As the number of samples from each of the sources is not the same, a purely statistical treatment would be misleading, and the observations and conclusion based on these samples must be regarded only as generalities. Table 16 summarizes the concentrations of the main anions and cations, as well as total hardness and total dissolved solids in surface and ground waters in the basin.

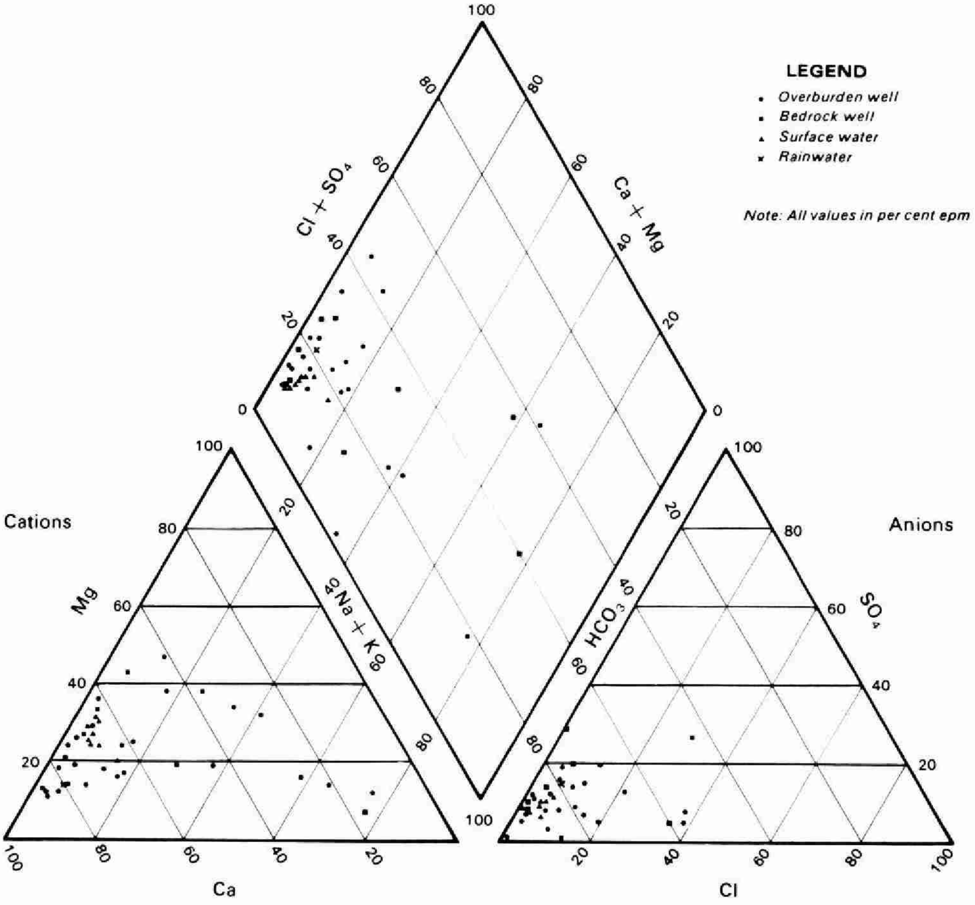


Figure 33. Chemical composition of waters in the Upper Nottawasaga River basin.

Table 16. Summary of Concentrations of the Common Ions and Chemical Parameters in Surface- and Ground-Water Samples

Chemical Parameter	Sample Source*	Concentrations (ppm)		
		Minimum	Maximum	Mean
Sodium	Ground water—overburden	2	148	27
	Ground water—bedrock	2	150	36
	Surface water	4	9	6
Potassium	Ground water—overburden	0.8	22	5
	Ground water—bedrock	1	13	4
	Surface water	0.9	20	4
Calcium	Ground water—overburden	13	151	88
	Ground water—bedrock	28	99	62
	Surface water	56	73	66
Magnesium	Ground water—overburden	8	51	18
	Ground water—bedrock	8	35	18
	Surface water	13	19	16
Bicarbonate	Ground water—overburden	185	444	309
	Ground water—bedrock	217	330	266
	Surface water	226	271	247
Sulphate	Ground water—overburden	0	86	30
	Ground water—bedrock	2	105	41
	Surface water	14	27	20
Chloride	Ground water—overburden	2	226	40
	Ground water—bedrock	1	115	27
	Surface water	2	12	8
Nitrate	Ground water—overburden	0.01	21	2.8
	Ground water—bedrock	0.01	1.2	0.30
	Surface water	0.32	1.5	0.73
Total Iron	Ground water—overburden	0.05	6.6	0.82
	Ground water—bedrock	0.05	3.0	0.53
	Surface water	0.35	4.8	1.5

*21 samples from overburden wells
9 samples from bedrock wells
8 samples from surface water

Sodium and Potassium

All natural waters contain measureable amounts of sodium. Most non-silicate sodium compounds are readily soluble in water, and halite (NaCl) is probably the most common mineral source of this ion. An additional source of sodium is ion exchange, in which the sodium ions on clay minerals are replaced by calcium or magnesium, thus enriching sodium in the water.

Sodium concentrations range from 2 to 150 ppm in ground water and from 4 to 9 ppm in surface water. Ground water from limestones contains relatively little sodium (average of 8 ppm), whereas waters from overburden and shale contain the largest concentrations. The probable presence of sodium chloride in shales, together with good ion exchange potential of the clays in shales, account for the large sodium concentrations in water in these environments.

Potassium values range from 0.8 ppm to 22.0 ppm, both extremes occur in ground water from overburden. Potassium and sodium are chemically similar substances, and the pattern of occurrence of potassium generally parallels that of sodium.

Calcium

The principal sources of calcium are from limestone bedrock and from overburden materials that consist, in part, of weathered limestone. Concentrations of calcium in water samples range from 13 ppm to 151 ppm in the overburden. In general, surface water and ground water in overburden and limestone all contain nearly equivalent amounts of calcium. Ground water in shale, however, contains slightly less (average of 59 ppm), this probably being due to ion exchange resulting in high sodium content in water as already noted.

Magnesium

Calcium and magnesium have similar chemical properties, and the patterns of distribution and occurrence in surface and ground waters are similar. Magnesium, however, is usually found in smaller concentrations in water. The range of magnesium concentrations is from 8 ppm in the shale, to 51 ppm in the overburden. Surface-water samples have the smallest range of concentrations and water from overburden sources the largest.

Bicarbonate

Bicarbonate ion in water results from the dissolution of carbonate rocks, notably limestone and dolomite, and from the hydrolysis of carbon dioxide gas. Bicarbonate concentrations are relatively uniform in both surface- and ground-water samples in the basin, ranging from a minimum of 185 ppm in an overburden well 235 feet deep, to a maximum of 444 ppm in another overburden well only 30 feet deep. In general, concentrations are largest in the overburden. Surface waters contain unexpectedly high concentrations of bicarbonate, possibly reflecting the large proportion of ground water in the streams at the time the water samples were taken (July 17-19, 1968).

Sulphate

Sulphate in water probably originates in large part from the dissolution of gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) which are disseminated throughout the overburden, present as impurities in limestone, and occur in association with shales.

Sulphate concentrations range from undetectable amounts in several shallow wells in the overburden, to 105 ppm in a bedrock well in shale where they are usually largest. Average concentration levels are 44, 38, and 30 ppm in the shale, limestone, and overburden, whereas surface waters contain an average of only 20 ppm.

Chloride

Most chloride probably originates from the dissolution of sodium chloride (salt) that occurs as a residue primarily in shales.

Chloride concentrations vary from 1 ppm in limestone to 226 ppm in overburden. However, the maximum value is suspected to be due to pollution by road salts in shallow overburden well 949, and this concentration is not considered indicative of natural water quality in overburden. Road salt pollution is also suspected in well 528 in which the chloride content was 116 ppm. Average natural concentrations are highest in waters from shale and overburden, and lowest in the limestone and stream waters.

Nitrate

Most nitrate in natural waters originates from organic sources, or from industrial or agricultural chemicals. Excessive amounts of nitrate are normally indicative of pollution. In the basin, nitrate in water samples ranges from 0.01 ppm in the overburden, limestone, and shale, to 21.0 ppm in one overburden well. Most values are less than 5 ppm and almost always less than 1.0 ppm in bedrock. Ground water tends to have highest nitrate concentrations in the overburden, possibly because shallow wells are most susceptible to pollution.

Total Iron

The concentrations of total iron are erratic as they vary from a low of 0.05 ppm in a 355-foot deep, overburden well to a maximum of 6.6 ppm in another overburden well only 15 feet deep. On the average, iron is most abundant in surface waters where much of it is probably in suspended solids. Ground-water samples from shale have the lowest concentrations.

Suitability of Water for Domestic Use

The suitability of water for domestic supplies is judged on the basis of two sets of criteria. The first set forms the basis for rejection of the supply when the limits are exceeded. The second set consists of recommended limits that should not be exceeded whenever more suitable supplies are available at a reasonable cost. Substances in the first category, such as arsenic and lead, may have adverse effects on human health when present in concentrations above the stated limits. The parameters in the second group are not normally considered health hazards, and include six parameters that are considered in this report: chlorides, iron, nitrate, sulphate, total dissolved solids, and hardness. The recommended limits of concentration for the following are (OWRC, 1967):

Parameter	Recommended Maximum Concentration (ppm)
Chloride	250
Total Iron	0.3
Nitrate	10
Sulphate	250
Total Dissolved Solids	500
Hardness	not specified

The above recommended maximum concentrations in domestic supplies are often exceeded without ill effects. However, consumers unaccustomed to high concentrations of certain constituents may notice differences upon first use, and thereafter become progressively more tolerant of the poor quality. Therefore, the evaluation of water quality depends, to a degree, on the sensitivity and the degree of acclimatization of individuals to the chemical quality of a particular supply.

Chloride

Chloride, in combination with magnesium or sodium, imparts a salty taste to water which may be detected at concentrations as low as 250 ppm.

All samples in the basin contained chloride concentrations of less than 250 ppm (Figure 34). There are six wells, all located just south and west of Tottenham, which were reported to contain "salty" water, but because these wells have been abandoned, no water samples were obtained from them.

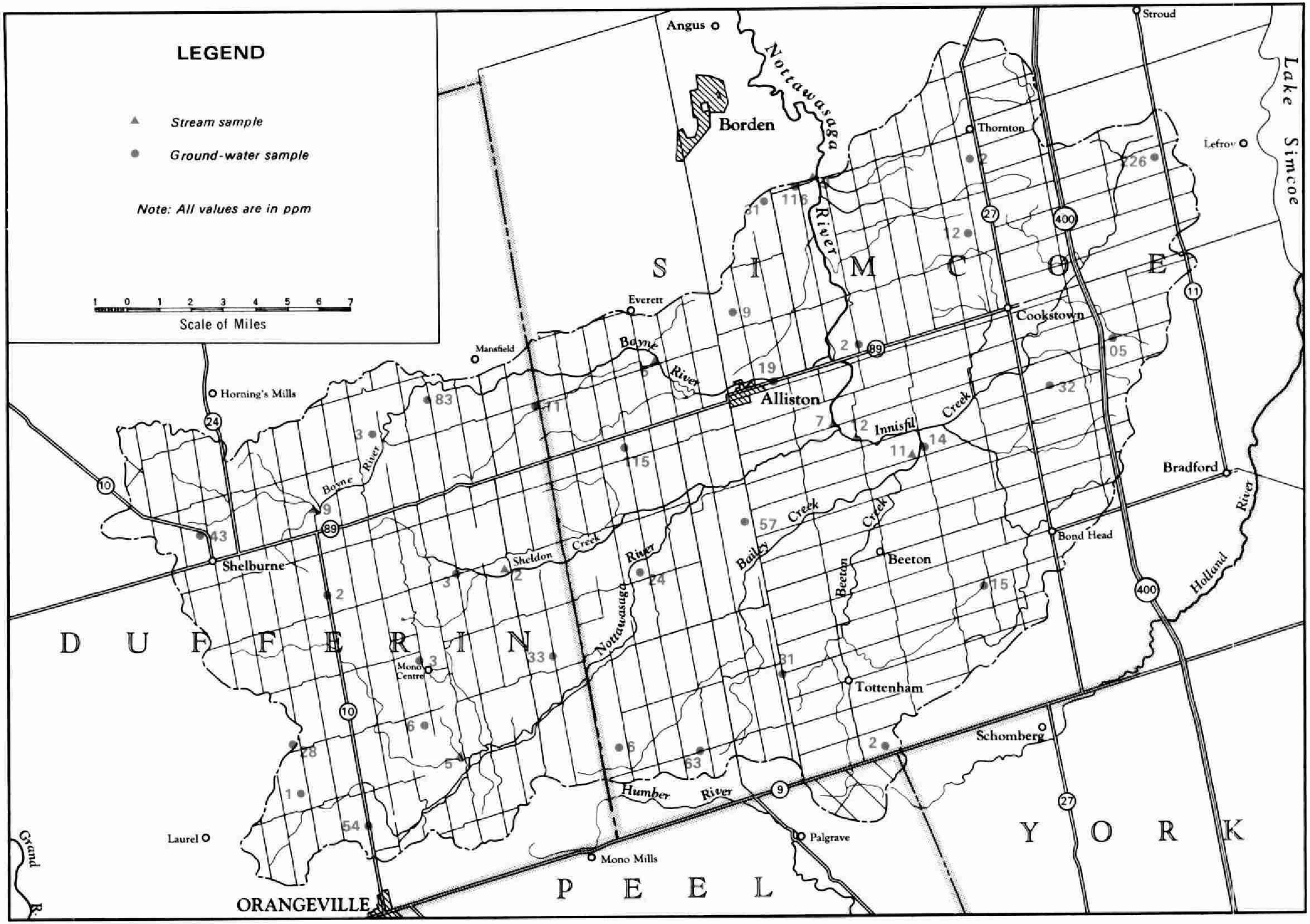


Figure 34. The concentration of chloride in surface- and ground-water samples in the Upper Nottawasaga River basin (sampled during July and August 1968).

Iron

Iron in water is mainly a nuisance. When iron precipitates from solution, it will stain laundry and porcelain, and it may impart a metallic taste to water. Excessive concentrations of iron can cause fouling of the mineral bed and valves in a water softener, and in such cases it is desirable to remove the iron (and manganese) before it reaches the softener. This can be accomplished by a combination of chlorination and filtration, or by aeration of the water.

Surface-water samples contained the highest amounts of total iron; the concentrations in all eight samples exceeded the recommended limit (Figure 35), and ranged from 0.35 ppm to 4.80 ppm. About one-third of the ground-water samples contained iron concentrations in excess of 0.30 ppm.

Nitrate

Nitrate in water may originate as a by-product of plant decomposition, and from animal wastes and fertilizers, and if it is derived from the latter two sources, water pollution is usually indicated. Nitrate in concentrations greater than 10 ppm in water is considered toxic to infants, but has little effect on adults. Nitrate can be removed only by distillation.

All samples contained detectable amounts of nitrate, even the deep wells in bedrock. However, only one water sample (from well 8 — 36 feet deep) contained nitrate in excess of the recommended limit of 10 ppm; the range of nitrate concentrations in other samples varied between 0.01 ppm and 7.8 ppm.

Sulphate

Sulphate in water does not usually present a serious problem to the acclimatized user, even when the recommended concentration limit of 250 ppm is exceeded. Large concentrations of sulphate in water may have a laxative effect on people accustomed to drinking water with lower concentrations.

None of the samples contained sulphates in excess of the recommended limit, and most samples contained less than 50 ppm.

Total Dissolved Solids

The concentration of total dissolved solids is a measure of the amount of dissolved minerals in the water, and as such, the parameter can be used as an indicator of the general suitability of a water for some uses. Waters containing less than 500 ppm of dissolved solids are considered to be satisfactory for domestic, stock, and some industrial uses.

There are nine samples, all from wells, with total dissolved solids concentrations greater than 500 ppm (Figure 36); however, the excesses are relatively small and therefore are not a deterrent to domestic use of the waters. Most of the nine samples were obtained from overburden wells less than 30 feet deep in surface till areas in the basin. All stream-water samples contained dissolved solids close to 300 ppm.

Hardness

Hardness is a measure of the amount of calcium and magnesium in solution. There are basically two types of water hardness: carbonate (or temporary) and non-carbonate (or permanent). Carbonate hardness is due to dissolved calcium and magnesium in the presence of carbonate and bicarbonate ions, and it can be removed either by boiling or by use of a water softener. Permanent hardness, which can be removed by a softener, is due to calcium and

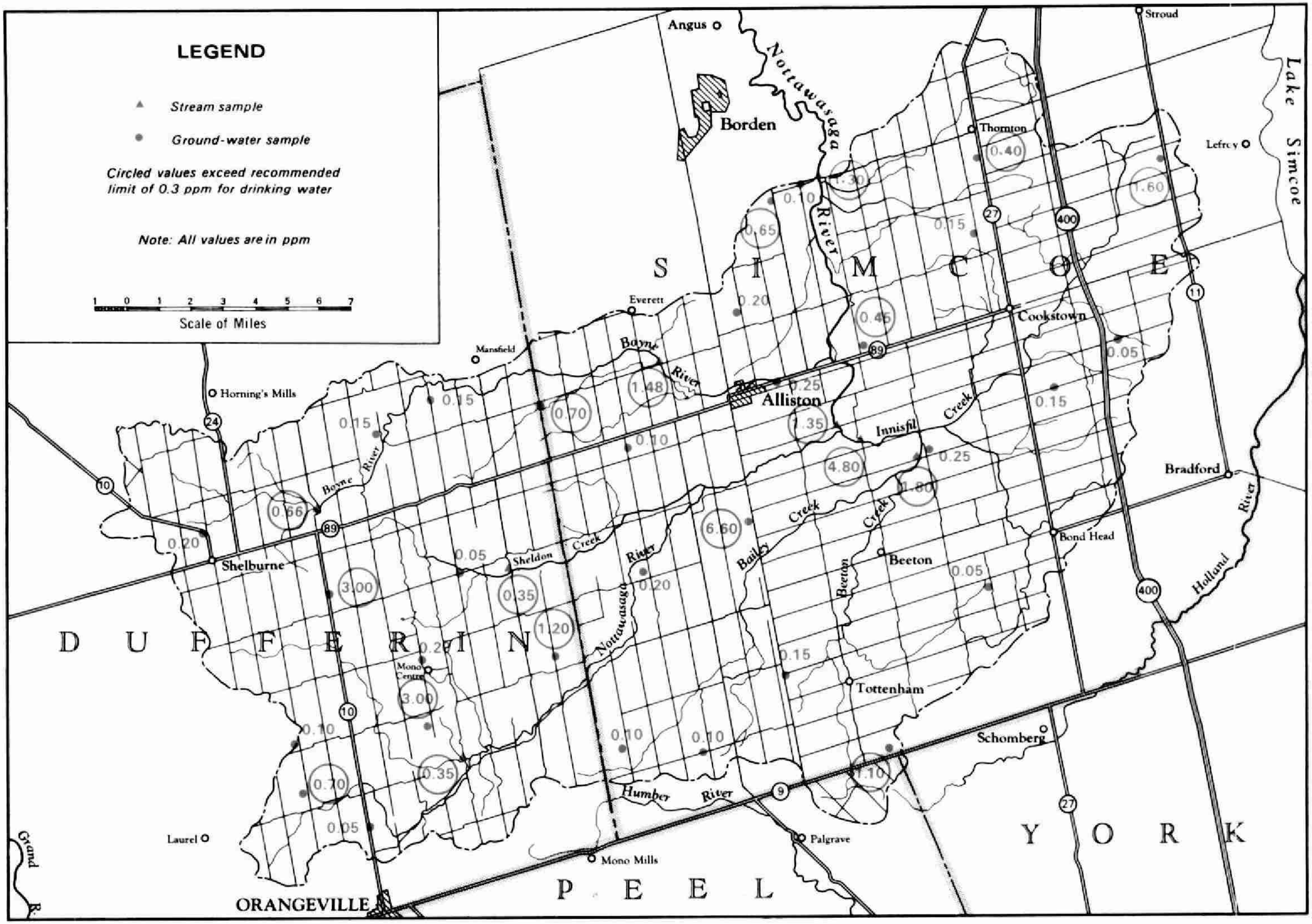


Figure 35. The concentration of total iron in surface- and ground-water samples in the Upper Nottawasaga River basin (sampled during July and August 1968).

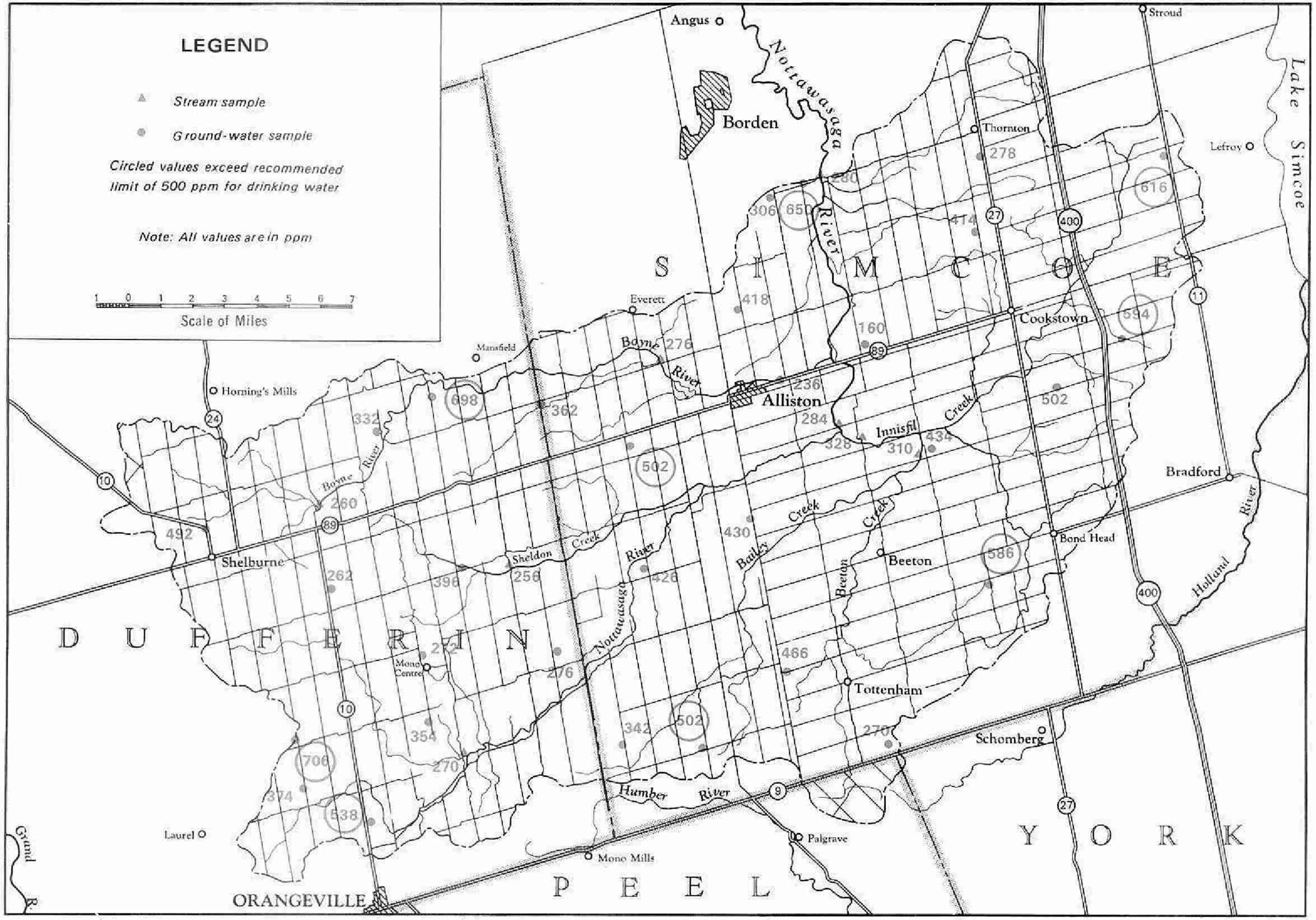


Figure 36. **The concentration of total dissolved solids in surface- and ground-water samples in the Upper Nottawasaga River basin (sampled during July and August 1968).**

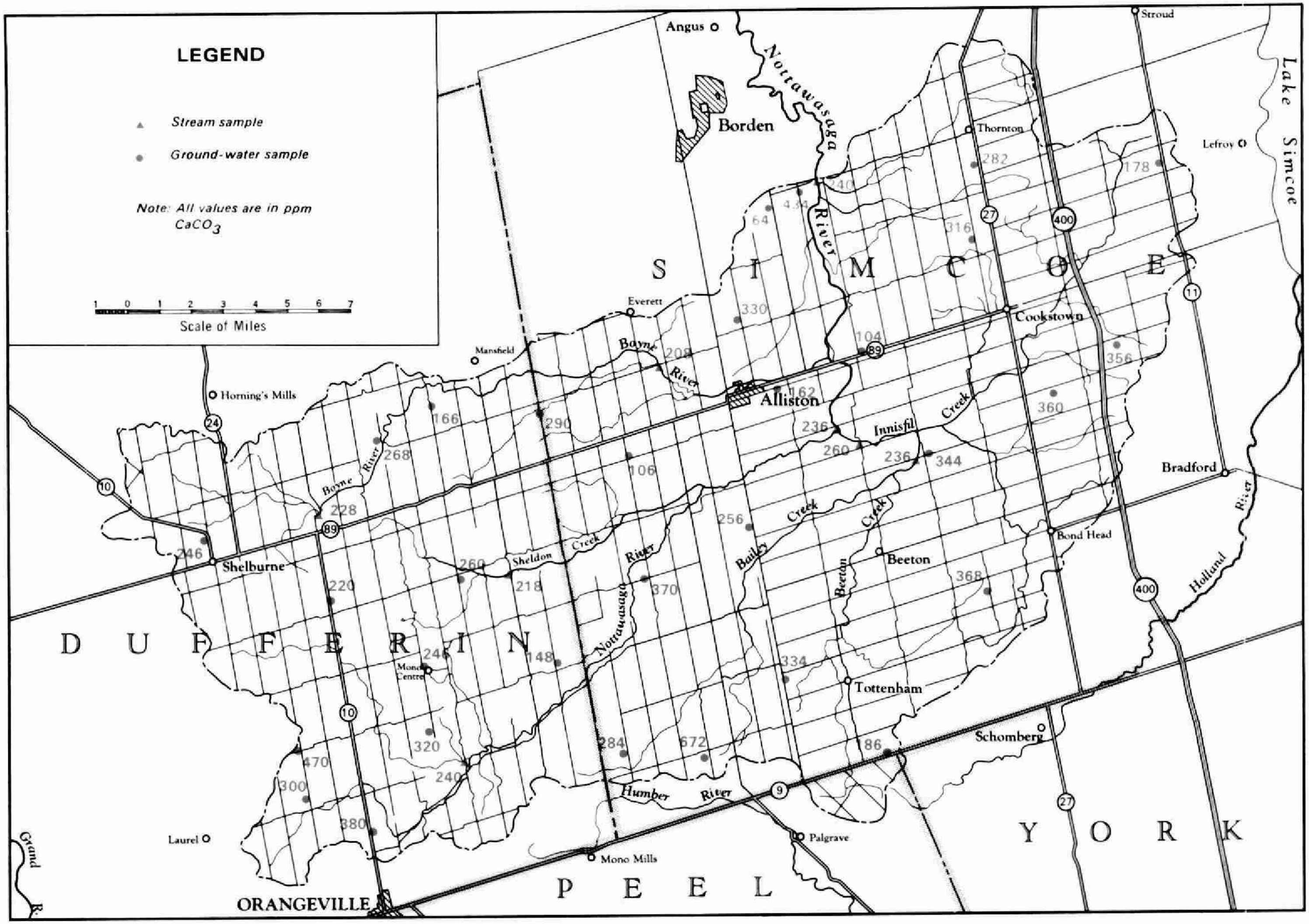


Figure 37. Total hardness of water in surface- and ground-water samples in the Upper Nottawasaga River basin (sampled during July and August 1968).

magnesium in the presence of mainly sulphate, nitrate, and chloride ions. The main objections to high carbonate hardness include the formation of a scale in water heaters and radiators, and the excessive amounts of soap required to produce a desired lather. In some instances, very hard waters may have an objectionable taste.

Water hardness is usually classified as follows:

Total Hardness (ppm $CaCO_3$)	Classification
less than 60	soft
60 — 120	moderately hard
121 — 180	hard
greater than 180	very hard

Water samples from both surface- and ground-water sources are generally hard to very hard. Hardness in ground-water samples ranged from 64 to 470 ppm, and in surface-water samples from 208 to 260 ppm (Figure 37). Ground waters from shale formations are generally softer than from limestones in the basin, but no generalities can be made regarding hardness of waters from overburden sources as there is a large fluctuation of values.

Suitability of Water for Irrigation

Many methods of classification are available (Hem, 1959), but the present classification of surface- and ground-water suitability for irrigation is based on the parameters of electrical conductivity (salinity hazard) and the amount of sodium compared to calcium and magnesium (sodium hazard). Large percentages of sodium in the soil will cause a decrease in soil permeability, which leads to inadequate soil aeration, poor drainage, and excessive salt accumulation. The electrical conductivity is a measure of the dissolved solids in water, which may be injurious to plants if present in large concentrations.

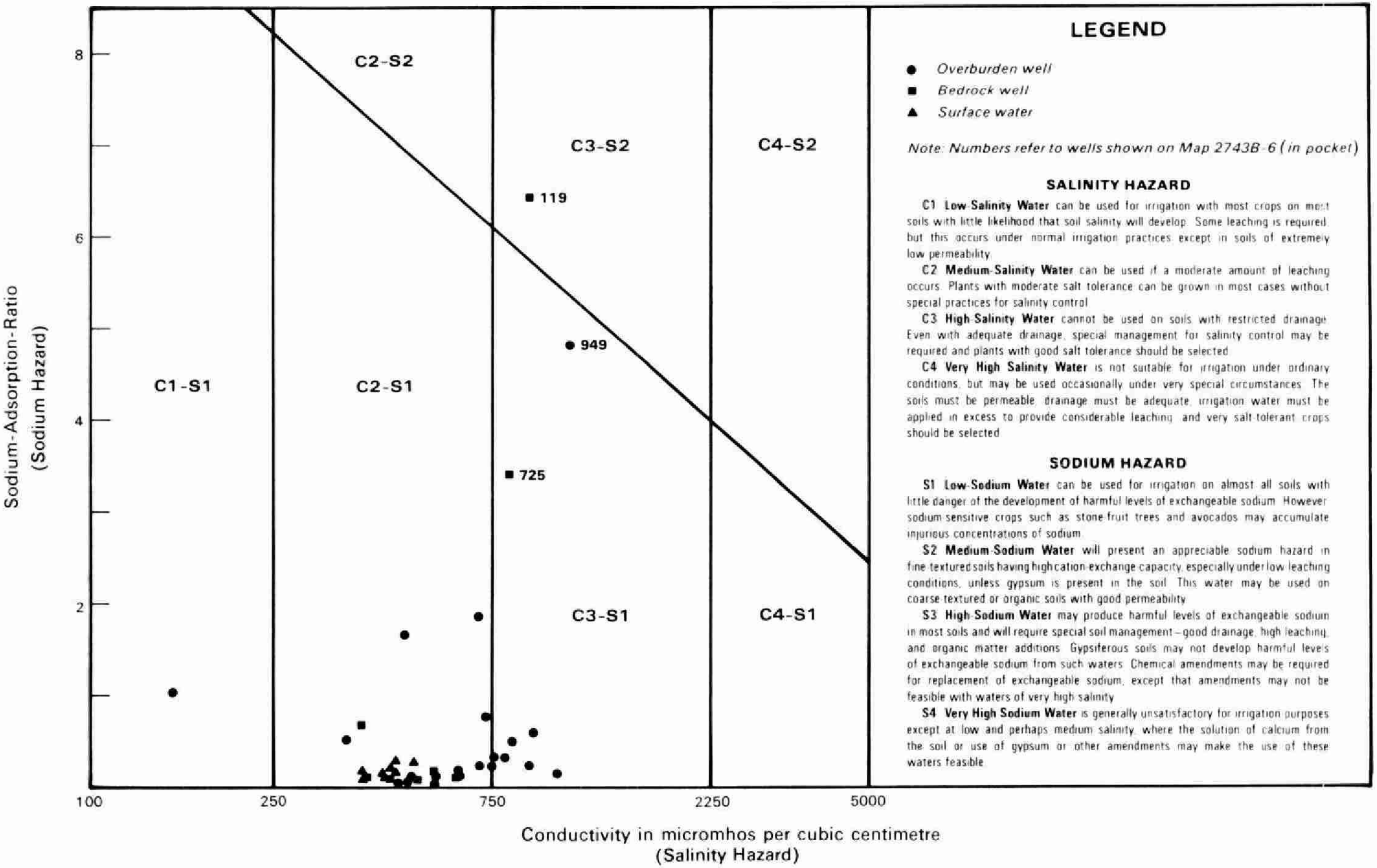
The method of classification is based on the Sodium-Adsorption-Ratio (SAR) and electrical conductivity as shown in Figure 38, and takes into account soil types, drainage, and salinity tolerances of irrigated crops. The SAR is defined by the equation (U.S. Salinity Lab. Staff, 1954):

$$\mathrm{SAR} = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

where all ionic concentrations are expressed in epm.

Except for one ground-water sample, from bedrock well 119, all water samples are classified in the low sodium hazard category of S1. The salinity hazard varies from C1 to C3, with waters in the C3 class not recommended for irrigation use in areas of poor soil drainage. All surface-water samples, and the majority of samples from bedrock and overburden wells, are in the C2-S1 class and are suitable for irrigation.

Water from bedrock wells in shale should be tested before use for irrigation because it tends to contain higher sodium concentrations than water from limestone or overburden sources.



Note: Numbers refer to wells shown on Map 2743B-6 (in pocket)

SALINITY HAZARD

C1 Low-Salinity Water can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

C2 Medium-Salinity Water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

C3 High-Salinity Water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

C4 Very High Salinity Water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

SODIUM HAZARD

S1 Low-Sodium Water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

S2 Medium-Sodium Water will present an appreciable sodium hazard in fine-textured soils having high cation-exchange capacity, especially under low leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

S3 High-Sodium Water may produce harmful levels of exchangeable sodium in most soils and will require special soil management – good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

S4 Very High Sodium Water is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Figure 38. Suitability of water for irrigation, classified on the basis of sodium and salinity hazards, Upper Nottawasaga River basin (diagram and legend after U.S. Salinity Laboratory Staff, 1954).

WATER USE AND DEVELOPMENT

Introduction

Water use in the upper Nottawasaga River basin is grouped and discussed according to three main uses of the resource: (1) municipal water supply, (2) irrigation, and (3) rural domestic, stock, recreation, and wildlife. Present uses by these groups are discussed in terms of the amount and adequacy of water, and where possible, recommendations are made regarding future sources when use begins to exceed demands. A detailed account is presented of the irrigation uses of water, together with the impacts created on the resource in view of the large amounts used from relatively small streams.

General areas of significant water use are presented on Map 2743B-7, which indicates the distribution of water use in the basin and complements subsequent discussions on use. This map shows the average annual amounts of water used in specific areas by municipalities, domestic and commercial users, and by irrigators. The three ranges of use indicated on the map represent actual average amounts of water used in the interval from 1965 to 1968. For municipal, and for domestic and commercial uses, the averages represent continuous use; for irrigation, the amounts represent average usage only for days when crops were irrigated.

Within good management practices, the degree of ground-water development depends on the rate of recharge and on the allowable amount of ground-water withdrawal based on maintaining satisfactory base flow in local streams. If more water is withdrawn from an aquifer than is recharged, a ground-water overdraft will occur. Such "mining", if allowed to persist, may lower static water levels until they are too low to permit desired withdrawal rates to be sustained, or until the water-bearing formation is dewatered. Short periods of overdraft may not be detrimental to well yields.

Conflicts in surface-water use commonly occur in areas where the resource is "over-developed" by individual users who are unconcerned with downstream demands. Programs of economic development in such areas must conform to the estimated water availability in order to achieve optimum water-resource utilization and conservation.

Municipal Use

Municipal water-supply systems exist at Alliston, Beeton, Cookstown, Shelburne, and Tottenham (Table 17). All of these systems utilize ground water.

Alliston

A ground-water survey for the Town of Alliston was carried out by Sobanski (1967), and much of the data used in this report has been adapted from that investigation.

The town's municipal system consists of wells located at four sites in the vicinity of the town (Map 2743B-1). All the wells are developed in the Alliston sand aquifer. The system has a calculated capacity of 1.2 million gallons per day (mgd) and an estimated peak demand, based on pumping data in 1966, 1967, and 1968, of 1.1 mgd. The average daily withdrawal during 1968 was 718,000 gallons and the average daily withdrawal during the maximum month was 868,000 gallons. Water shortages have occurred during peak hours in the summer months.

Table 17. Average Daily Water Use by Five Municipalities, During the Period 1966 to 1968

Municipality	System Capacity (gpd)	Average Daily Consumption (gal)	Per Capita Consumption (gpd)
Alliston	1,200,000	754,000	240
Beeton	300,000	74,800	78
Cookstown	60,500	20,000	28
Shelburne	360,000	110,000	85
Tottenham	72,000	39,900	83

Industrial use accounts for a large proportion of the total municipal consumption. Salada Foods Limited, for example, has a maximum daily demand of about 750,000 gallons during the peak season from January to March, and a minimum demand of 300,000 gallons in midsummer.

The deep sand aquifer in which the existing municipal wells are constructed offers the best source of additional water for Alliston. Favourable areas of exploration for new wells are located to the east and to the north of town, in agreement with the delineated aquifer extent shown on Map 2743B-5. Additional wells in the sand formation can be expected to yield several hundred gallons per minute, but as more wells are developed in the aquifer, the possibility of interference will require a well-field management plan to ensure proper well spacing for optimum yields.

Beeton

This village of approximately 1000 persons is supplied from a municipal well completed in sand at 166 feet and a 250,000 gallon reservoir filled from natural springs. The well is rated at 70,000 gpd (50 gpm) and the total system is capable of 300,000 gpd. The average daily demand on the system in 1968 was 187,000 gallons.

The sand deposit in which the municipal well is constructed appears to be part of the same sand in which Alliston's municipal wells are located. This deep lacustrine sand complex is a favourable source of water for additional municipal wells for Beeton. The most productive zones in this sand will have to be determined by test drilling, and are probably located to the north or east of the village, as suggested by Whitehead (1969). At least some of the test wells should penetrate the full overburden thickness of about 300 feet so that wells can be developed in the best formations in the overburden.

Cookstown

One municipal well, with a rated capacity of 60,500 gpd (42 gpm), serves the water-supply needs of approximately 700 residents in the Village of Cookstown. The average daily pumpage for 1968 was about 20,000 gpd. The demand on the average day of the maximum month (June 1967) was 23,000 gallons and the maximum-day consumption during this month was 51,000 gallons.

The system is capable of supplying present needs; however, when it becomes necessary, additional wells to augment the existing municipal system should be drilled to the south or east of the village where the Alliston sand aquifer is probably located at an elevation of 500 feet or slightly higher. Production from the sand may be several hundred gallons per minute and will depend on the thickness and coarseness of the deposit. Little problem is foreseen in obtaining additional supplies of ground water to keep pace with expected expansions in water consumption.

Shelburne

The two municipal wells serving Shelburne are constructed in the Amabel dolomite. The combined capacity of these wells has been rated at about 360,000 gpd or 250 gpm. Average daily use in 1968 was 176,700 gallons, and the demand on the maximum day (Dec. 13, 1968) was 957,700 gallons or 665 gpm.

Wells in the Amabel Formation can quite easily yield 100 gpm or more; however, where a number of wells tap the same water-bearing zone, adequate spacing of the wells is necessary to avoid well interference. Deeper drilling into the dolomite usually results in increased yields, but wells that penetrate beyond about 120 feet of dolomite, and those that are drilled through the dolomite, do not produce appreciably larger yields. In any case, the Amabel Formation is the best bedrock aquifer in the area.

Tottenham

The village is supplied by two deep overburden wells which have a combined capacity of about 72,000 gpd or 50 gpm. Estimates for 1967 indicate an average daily demand of 40,000 gallons and a maximum-day demand of 80,000 gallons or 55 gpm. A drilling program completed in 1970 has resulted in an additional well with a reported yield of 600 gpm, and consequently the improved municipal system will be capable of supplying a population of at least 8000 people (excluding large industrial demands). The assessed population in 1968 was 909; however, new residential areas are developing rapidly.

Additional wells for the village should be located towards the south where sands and gravels occur beneath the surficial till. There is also a good probability that the outwash gravels observed at the surface south of Tottenham extend beneath the till towards Tottenham. Partially penetrating wells developed in these confined sands and gravels have theoretical yields in excess of 100 gpm, and a properly developed and fully penetrating municipal well in similar deposits should yield as much and more.

Waste Disposal

Four municipalities in the basin have communal sewage treatment systems: Alliston, Beeton, Shelburne, and Tottenham (Table 18). In addition, there is a large private system in Alliston which belongs to Salada Foods Ltd. and which has a design capacity of 750,000 gpd. Beeton's system is the smallest with an estimated capacity of about 96,000 gpd. Both Shelburne's and Alliston's systems were overloaded during 1970. The average daily flow at Shelburne was 200,000 gpd, and daily flow through the Alliston plant was about 400,000 gpd, or twice design capacity.

The combined effluent discharge from the Alliston municipal and Salada Foods Ltd. systems during 1970 was approximately 18 per cent of the ten-year, seven-day low flow in the Boyne River at station 10. The average daily effluent discharge from the Beeton system was only 5 per cent of the ten-year, seven-day low flow in Beeton Creek. Shelburne and Tottenham discharge effluents into streams whose low flows range from intermittent to about one cubic foot per second. Discharges from the Beeton and Tottenham sewage lagoons are on a semi-annual basis and occur during periods when streamflows are large, but the continuous discharge from the Shelburne lagoon has resulted in impaired stream-water quality which was noted during a biological investigation of stream water during the summer of 1968.

It is expected that, except for Beeton, expanded facilities will have to be provided for all municipalities in the near future, especially for Alliston and Shelburne where the systems have been overloaded on a continuous basis. A new plant is scheduled to be built at Alliston in 1972.

Table 18. Sewage Treatment Systems in the Upper Nottawasaga River Basin River (1970)

Location	Type of System	Capacity (gpd)	Type of Treatment	Average Daily Effluent Discharge (cfs)	Receiving Stream	Remarks
Alliston	Communal	200,000	Modified activated sludge	0.74	Boyne River	Secondary treatment; average flow of about 400,000 gpd; system overloaded; new plant to be build in 1972.
Alliston	Private (Salada Foods Ltd.)	750,000	Activated sludge, aeration lagoon, plus two stabilization lagoons.	0.93	Tributary of Boyne River	Secondary treatment plus polishing lagoons; flow out of system of about 500,000 gpd.
Beeton	Communal	96,000	Lagoon	0.08	Beeton Creek	Area of lagoon is 14.8 acres; discharges semi-annually; approximately 45% of Beeton's residence is connected to the system; flow through the system of about 45,000 gpd.
Shelburne	Communal	132,000	Lagoon	0.19	Tributary of Boyne River	Area of lagoon is 13.2 acres; discharge continually; average flow about 200,000 gpd; system overloaded.
Tottenham	Communal	122,000	Lagoon	0.37	Beeton Creek	Area of lagoon is 14.0 acres; discharges semi-annually; average flow of about 102,000 gpd.

Use of Water for Irrigation

Crop irrigation in the upper Nottawasaga River basin depends primarily on stream water. Withdrawals for irrigation from streams often coincide with periods of natural low flow, and this results in frequent streamflow depletions that interfere with downstream use of water. Flows in Bailey Creek near Beeton and in some smaller streams in the same vicinity have on occasion dried up momentarily during days of concentrated withdrawals from them. Because of this keen competition for stream water, analyses are made of the effects of stream-water withdrawals on low streamflows for recurrence intervals of 3 and 10 years. The uses of stream water will be discussed separately in each of the following sub-basins: the Nottawasaga and Boyne rivers, and in Innisfil, Bailey, and Beeton creeks.

Information on stream-water withdrawals during 1966 was obtained from water-taking permits on file with OWRC. Such permits are required whenever surface- or ground-water takings exceed 10,000 gpd; permits are not required for domestic, stock, and fire fighting uses. The 1966 irrigation season was selected for analysis because it was considered a "dry" period. The July precipitation at Beeton was one of the lowest on record, and the lowest daily flows recorded in Bailey Creek near Beeton occurred during that year.

In 1966 there were 64 permits to take stream water in the basin. Only 51 water-taking records for the year were returned to the Commission, but the amount of water used for irrigation during the year was estimated for all 64 permits. The estimates were based on the ratio of the number of permits in force to the number of water-taking records returned in each area under study. The following is a summary of the permit records for 1966:

Sub-basin	Number of Permits	Number of Water-Taking Records Returned	Number of Permit Holders that Irrigated
Nottawasaga River	28	22	17
Boyne River	12	11	9
Innisfil Creek	6	6	4
Bailey Creek	11	7	6
Beeton Creek	7	5	4
TOTAL	64	51	40

Information about water-taking records and estimates of withdrawals from individual streams are given in Table 19. The average rate of daily withdrawal and the maximum daily withdrawal allowed by permit from all streams (above specified gauging stations) are compared with estimated seven-day minimum flows in Table 20. In the latter table, the average rate of daily withdrawal is the sum of the average individual daily takings for all permits, and since it does not take into account the actual dates of irrigation, probably represents the maximum average daily rate. The maximum daily withdrawals allowed by permits (Column 4) were calculated by summing the allowable daily withdrawals for all permit holders upstream of the indicated gauging stations.

The three primary crops grown in the watershed are potatoes, tobacco, and sod, and they are cultivated mainly on the sand plain adjacent to the Nottawasaga River and its tributaries around Alliston, Beeton, and Cookstown (Map 2743B-7). The "other" category in Table 19 includes various market-garden crops and golf courses.

In 1966, the earliest irrigation occurred on May 16 and the latest on September 28. The season for sod irrigation was the longest. The average number of days of sod irrigation was 40. Tobacco was irrigated for an average of 15 days and potatoes were irrigated about 13 days; the period of irrigation for these lasted from about mid-June to early August.

Stream-water withdrawals for irrigation in 1966 amounted to about 208 million gallons (Table 19) and the average daily rate of taking was approximately 24 cfs.

Table 19. Stream-Water Withdrawals for Irrigation During 1966

Stream	Crop	Number of Withdrawals / Number of Records Returned	Estimated Total Withdrawal During Year (1000 gallons)	Earliest Irrigation	Latest Irrigation	Average Number of Irrigation Days	Average Rate of Daily Withdrawal (cfs)
1	2	3	4	5	6	7	8
Nottawasaga River	Tobacco	10/12	57,200	Jun 1	Aug 8	15	6.36
	Potatoes	7/10	49,000	Jun 28	Jul 28	12	6.87
	Total	17/22	106,200				13.23
Boyne River	Tobacco	3/4	11,923	Jun 21	Aug 8	17	1.25
	Potatoes	3/4	15,500	Jul 5	Aug 8	9	5.08
	Sod	2/2	8,019	May 23	Sep 17	36	0.34
	Other	1/1	131	Jun 18	Aug 6	17	0.02
	Total	9/11	35,573				6.69
Innisfil Creek	Tobacco	0/1	—	—	—	—	—
	Potatoes	1/1	2,101	Jun 28	Jul 28	16	0.24
	Sod	1/2	3,288	Jun 30	Aug 8	16	0.38
	Other	2/2	4	—	—	—	—
	Total	4/6	5,393				0.62
Bailey Creek	Tobacco	1/1	755	Jun 22	Jul 26	22	0.54*
	Potatoes	3/4	7,360	Jun 27	Jul 16	20	
	Sod	1/1	42,264	May 16	Sep 28	96	0.82
	Other	1/1	540	Jul 15	Jul 15	1	1.00
	Total	6/7	50,919				2.76

Table 19 (continued). Stream Water Withdrawals for Irrigation During 1966

Stream	Crop	$\frac{\text{Number of Withdrawals}}{\text{Number of Records Returned}}$	Estimated Total Withdrawal During Year (1000 gallons)	Earliest Irrigation	Latest Irrigation	Average Number of Irrigation days	Average Rate of Daily Withdrawal (cfs)
1	2	3	4	5	6	7	8
Beeton Creek	Potatoes	$\frac{2}{2}$	6,420	Jun 27	Jul 26	17	0.56
	Sod	$\frac{1}{2}$	3,528	Jun 15	Aug 12	14	0.47
	Other	$\frac{1}{1}$	500	Jul 5	Jul 30	12	0.07
	Total	$\frac{4}{5}$	10,448				1.10
			SUMMARY				
Upper Nottawasaga River Basin	Tobacco	$\frac{14}{18}$	69,878	Jun 1	Aug 8	15	7.61
	Potatoes	$\frac{16}{21}$	80,381	Jun 27	Aug 8	13	13.69
	Sod	$\frac{5}{7}$	57,099	May 16	Sep 28	40	2.01
	Other	$\frac{5}{5}$	1,175	Jun 18	Aug 6	7	1.09
	Total	$\frac{40}{51}$	208,533				24.40

* Includes withdrawal for tobacco.

Table 20. Comparison of Daily Stream-Water Withdrawals in 1966 With Seven-Day Minimum Flows for T = 3 Years and T = 10 Years

Stream	Station Number	Average Rate of Daily Withdrawal Above Station (cfs)	Maximum Daily Withdrawal Allowed by Permit Above Station (cfs)	Seven-Day Minimum Flow (cfs)	
				T=3 Years	T=10 Years
Beeton Creek	28	1.10	4.16	2.0	1.5
Boyne River	10	6.69	9.01	11.7	9.5
Bailey Creek	2ED-4	3.76	12.1	6.0	4.5
Innisfil Creek	18	4.38	14.3	9.0	6.7
Nottawasaga River	2ED-3	24.4	46.8	61.0	48.0

Nottawasaga River

The largest amount of irrigation water is taken from the Nottawasaga River. The estimated total withdrawal during the 1966 season was 106 million gallons, or 51 per cent of the total taking in the basin. Most of the water was extracted downsteam from gauging station 2ED-101 (Map 2743B-2). Tobacco and potatoes are the two main crops irrigated from the river. Tobacco accounted for 54 per cent of the water used, and 46 per cent was used for irrigating potatoes.

The average withdrawal during days of irrigation from the Nottawasaga River was 24.4 cfs and the total allowed by permits amounted to 46.8 cfs. The average daily withdrawal in 1966 was 51 per cent of the seven-day minimum flow for an average recurrence interval of 10 years (T = 10) at the Baxter gauge (2ED-3), and the amount of water allowed by permits is only 2.5 per cent less than this minimum flow. It therefore seems that present irrigation demands from the lower portion of the Nottawasaga River can be met successfully most of the time.

Boyne River

The estimated volume of water taken for irrigation from the Boyne River in 1966 was 35.6 million gallons. Irrigation of potatoes, tobacco, and sod accounted for 44, 34, and 22 per cent of this total, respectively. Most withdrawals occurred in the section between Earl Rowe Park and the stream confluence with the Nottawasaga River.

The average withdrawal from the Boyne River on days of irrigation during 1966 was estimated to be 6.7 cfs, which is equivalent to 70 per cent of the seven-day minimum flow for T=10 years at streamflow gauging station 10. The maximum daily withdrawal allowed by permits was 95 per cent of the ten-year, seven-day minimum flow.

Innisfil Creek

The amount of irrigation water taken from Innisfil Creek in 1966 was approximately 5.4 million gallons. There were only six permits issued for taking water from this stream itself, but the maximum withdrawal allowed by permits from the entire Innisfil Creek sub-basin amounted to 14.3 cfs. The average withdrawal from the stream system for irrigation during 1966 was 4.38 cfs per day, which is 65 per cent of the seven-day minimum flow for the ten-year recurrence interval at gauging station 18. The amount of the water permitted for withdrawal was 1.6 times the three-year, seven-day minimum flow, and 2.1 times the ten-year, seven-day minimum flow.

Bailey Creek

Withdrawal of stream water from Bailey Creek in 1966 amounted to about 50.9 million gallons, of which 83 per cent was used for sod irrigation by one permittee. Irrigation of potatoes required 14 per cent of the water taken, and the remaining 3 per cent was used for irrigation of garden crops.

The average seasonal withdrawal from Bailey Creek during 1966 was about 3.8 cfs. This withdrawal was equal to 84 per cent of the ten-year, seven-day minimum flow for Bailey Creek near Beeton. The maximum daily withdrawal permitted totalled 12.1 cfs, which was 2.0 and 2.7 times the seven-day minimum flow for recurrence intervals of three and ten years, respectively.

Irrigation can be expected to result in serious interference with streamflow in Bailey Creek if most of the permitees irrigate at the same time.

Beeton Creek

Permit holders withdrew 10.4 million gallons of water from Beeton Creek in 1966, mainly for the irrigation of potatoes and sod. Sixty per cent of the water was used for potatoes and 34 per cent for sod.

The average withdrawal on days when crops were irrigated during 1966 was 1.1 cfs, or 73 per cent of the ten-year, seven-day minimum flow at streamflow gauging station 27. The maximum withdrawal allowed by permits amounted to 4.16 cfs, which was 2.1 and 2.8 times greater than the three-year and the ten-year, seven-day minimum flows. As in Bailey Creek, interference with streamflow in Beeton Creek during the peak period of irrigation can occur.

Rural Domestic, Stock, Recreation, and Wildlife

Except for some stock watering, rural water needs are met by ground water from dug, bored, and drilled wells. Stock are watered from these sources as well as from ponds and streams.

The rural domestic water demand throughout most of the basin is less than 4000 gpd per square mile. This estimate assumes a consumptive rate of 100 gpd per capita and an average population of 4 persons per farm. In the vicinities of hamlets, the demand increases to as much as 12,000 gpd per square mile. No estimates of stock-watering use were made.

Recreation and wildlife demands on water are discussed in detail in the Nottawasaga Valley Conservation Report (1964) and the reader is referred to that report for discussions regarding these uses.

WATER RESOURCES MANAGEMENT

Introduction

The purpose of this section is to outline a number of situations in the watershed where management of surface and ground water is of primary importance. The aim of such management would be to guide the development and conservation of these resources, and in some instances, to remedy past problems that may recur. In discussing the situations, background data about surface and ground water are presented, together with basic guidelines on management for the development of water in specific areas. However, these guidelines, which are based primarily on water-quantity information, must be applied in conjunction with water-quality criteria for specific uses. Chemical quality of surface and ground waters has been discussed in this report, but biological quality should be considered, especially in surface water, before water-management policies for specific areas are formulated.

The Nottawasaga Valley Conservation Report, 1964, is an authoritative reference on water-resources management as applied to the land-resources, forest and wildlife conservation, and opportunities for recreational development. It should be consulted whenever detailed information on these subjects is needed in management planning.

Control of Flowing Wells

Uncontrolled flow of water from wells is often a needless waste of the resource. Wells are too often left to flow without any particular use being made of the water. In some instances, the water from flowing wells floods large areas and erodes channels across valuable agricultural lands. In addition to causing damage or inconvenience on the surface, flowing wells represent a release of hydrostatic pressure from subsurface formations, which in time will result in decreased water levels in wells, initially in the immediate vicinity, and ultimately at larger distances from the flowing wells. It is not uncommon to find that with time, free discharge has decreased or ceased altogether in some wells.

In large areas of flowing wells, management policies are required to conserve the groundwater resource, as well as to prevent the lowering of water levels in existing wells to the point where some wells may "go dry". The OWRC has jurisdiction over flowing wells that cause property damage or result in water-use conflicts among residents in an area. However, "preventive" management in flowing-well areas should be practised by local residents on the basis of individual concerns about conservation of the resource.

A large area of flowing wells exists on the Lake Algonquin sand plain (Map 2743B-5). Deep wells drilled in the area will almost invariably flow, especially if they penetrate the Alliston sand aquifer. Water commonly flows from these wells where surface elevations are less than 750 feet. To avoid flowing wells, drilling on the sand plain should be confined to depths of less than about 100 feet. If deeper drilling is anticipated, surface casing should be installed to control flow in the event that it does occur. At the fringes of the sand plain, wherever possible, deep drilling should be limited to surface elevations higher than 775 feet, above which wells usually do not flow.

Flowing-well areas north of Tottenham, near Shelburne, and in the low, swampy area south of Elba are not extensive, but an awareness of flowing wells in these locations should guide well-construction practices to provide for the control of flow in future wells.

Hazards of Pollution in Surface Sand and Gravel Areas

There are extensive areas of sand and gravel east of the Niagara Escarpment and on the Lake Algonquin sand plain where ground-water pollution is a particular hazard. These porous deposits will readily transmit contaminants from surface sources to ground water, and because of their generally good permeability, ground-water pollution may become widespread in a relatively short period of time. If ground water does become polluted, there is also a good chance of surface-water pollution because flow in many of the streams in the kame-deposit areas consists, for the most part, of ground water.

Garbage dumps should not be located indiscriminately in areas where sands and gravels exist at surface. The numerous abandoned gravel pits south and southeast of Hockley, as well as several on the sand plain northeast of Alliston, are inviting locations for solid-waste dumps. It should be a general rule that these gravel pits not be used for dumping garbage, and exceptions should be made only after extensive investigations have ruled out any chances of polluting the ground water. Dumping on the sand plain is particularly a hazard because water-table depths are often less than 10 feet and ground-water pollution is all too possible. In hummocky kame areas the water-table depths often exceed 30 feet and the chances of pollution are less; however, great care must be taken even in areas where the water-table is deep. Liquid wastes should not be discharged in any areas of surface sand and gravel, unless it has been determined that there is no serious hazard of pollution.

Pollution of ground water by road salts is a hazard on the sand plain and less common in areas of semi-permeable surface deposits. To avoid obtaining polluted water in areas where salting occurs, domestic wells should be located as far away from the roads as possible and at ground elevations above the road bed, or alternatively, be constructed in aquifers below the surface sand on the plain.

Municipal Well Field Planning

Five municipalities obtain their water supplies from wells. In each situation, management of the ground water in the aquifers is necessary. Two concerns should be primary in such management:

(1) the allowable degree of interference with streamflow and with supplies obtained from other wells, and

(2) the relation of the extraction rate to the perennial yield.

Well interference was evident at Shelburne when a second municipal well was drilled only a short distance from the first well. Consequently, the combined withdrawal from both wells had to be limited to a little more than the capacity of one of the wells. At Alliston, municipal wells at four sites tap various portions of the Alliston sand aquifer. In this situation the degree of interference, if any, has not been evident, but water levels in the aquifer should be monitored continuously to determine the perennial yields from the aquifer. In addition, future municipal wells must be properly spaced from existing wells to minimize well interference and to prolong the "useful life" of the aquifer.

To evaluate aquifer response to withdrawals of water, and thereby avoid "mining" of aquifers, constant observation of piezometric levels is necessary in all high-capacity aquifers. It is preferable to have continuous records of water levels, but if continuous recording is not practicable, manual measurements at periodic intervals will suffice. In any case, it is recommended that observation wells be constructed in each aquifer from which the five municipalities obtain their water supplies.

Stream Water Development Based on Low Flows

In planning surface-water development in any particular area in the basin, the estimated annual seven-day low streamflows shown in Figure 24 should be considered. The flows on the map are for an average recurrence interval of 10 years, and this should be kept in mind when interpreting the adequacy of the seven-day low flows for particular use. Many headwater streams are intermittent or have flows less than 1 cfs over relatively long reaches, but more favourable conditions should exist during most years. Throughout most of its length the Nottawasaga River has low flows greater than 5 cfs, and offers a relatively large quantity of water for future development. Such development, however, must be in harmony with natural stream functions and with the requirements of downstream users of the resource.

The effects of on-stream ponds on downstream water temperatures should be evaluated prior to the construction of ponds on intermittent streams in the headwaters of the Boyne and Nottawasaga rivers, as well as on most of Sheldon Creek. The headwater streams of Sheldon Creek depend mainly on ground water and are therefore especially suitable for certain species of fish that require a cold-water habitat. The temperature ranges of all streams in the watershed are documented in the Nottawasaga Valley Conservation Report, 1964, which also discusses the effects of water temperature on fish life.

Management of Headwater Swamps and Streams

Headwater swamps in the western portions of the basin serve as reservoirs that slowly release water to streams, thus maintaining flow in headwater streams of the Boyne and Nottawasaga rivers over relatively long periods of time. The extensive swamp south of Elba sustains flow in the stream that flows through it, and also provides a good habitat for fish and many varieties of wildlife. Its preservation should be considered essential in the realm of water resources in the area. The preservation of each of the smaller swamps near the western boundary of the basin should be considered on its own hydrologic and ecologic merits.

The extensive swampy areas on the Innisfil Creek sand plain and the large tract of swampland west of Beeton should be evaluated individually as to their role in surface- and ground-water relationships in the respective areas. Some of the swampland east of Cookstown is being reclaimed and used for vegetable gardens. Because such reclamation to date has been on a small scale, its effects on surface and ground water are probably minimal. Larger scale reclamation projects, however, must evaluate the hydrologic significance of such reclamation, as well as the effects on wildlife which abound in these swamps. One foreseeable detriment of swamp drainage will be to lower the water-table, which in turn may reduce base flow to streams. Investigation should be undertaken prior to drainage to quantify the surface- and ground-water interrelationships, and the results should be weighed in accordance with economic and ecologic priorities in the involved areas.

Management of Water for Irrigation

A major use of stream water in the basin is for irrigation. Because of its relatively large low flows, users on the main stream of the Nottawasaga River do not normally experience water shortages or conflicts in water use. This, however, is not the case in streams in the Innisfil Creek sub-basin where large stream-water withdrawals from Beeton and Bailey creeks, as well as from Innisfil Creek itself, have in the past resulted in significant streamflow reductions. Some of the large withdrawals have resulted in insufficient flow for downstream users.

The construction of on-stream ponds should be carefully regulated because even small reservoirs can increase water temperatures downstream, which in turn may have significant effects on fish. Off-stream ponds in the "morainic deposits" south of Beeton (Map 2743B-4) are one means of storing stream water with minimal effects on stream-water temperatures.

Damming of stream water is not always physically or economically possible, in which case alternative solutions to water shortages must be sought. In those areas of irrigation that are located on the Algonquin sand aquifer, or that overlie the Alliston sand aquifer (Map 2743B-5), the development of ground water for irrigation is recommended. Dugout ponds constructed on the sand plain may provide easy access to shallow ground water. At times of low flow in the streams, withdrawal from "dugouts" will provide, in most instances, sufficient water for irrigation, and often they may be used as the main source of water. In the construction of dugout ponds, allowance must be made for natural water-table fluctuations of approximately five feet in addition to the storage required for irrigation.

In areas where the water-table depths on the sand plain exceed 10 to 15 feet, dugout ponds may not be economical to construct, and deep wells tapping the Alliston sand aquifer may provide an alternative source of supply. Precautions should be taken to control flowing wells in areas where the ground-surface elevations are less than 750 feet. In most instances the yields from the deep wells will be sufficient to maintain irrigation during periods of low flow in streams. With proper well construction, yields of more than several hundred gpm should be readily obtainable, in which case deep wells may serve as the sole source of water for irrigation.

SUMMARY AND CONCLUSIONS

An evaluation of the water resources of the upper Nottawasaga River basin is presented to provide a basis for water-management planning.

Field investigations during 1968 involved the mapping of surface geology, periodic measurement of streamflow, surface- and ground-water sampling, and the installation of 21 piezometers and three streamflow recording stations in the basin.

The basin has four distinct physiographic regions (Figure 2, in pocket):

1) Escarpment Upland region
2) Kame Hills region
3) Ground Moraine region
4) Sand Plain region

The Escarpment Upland region is characterized by high land elevations between 1500 and 1700 feet and consists mainly of a rolling till plain. The Kame Hills region is separated from the Escarpment Upland region by the Niagara Escarpment and contains hummocky topography in which the surface deposits are mainly kame. The Ground Moraine region consists of gently undulating till plains which form most of the northern and southern drainage divides in the eastern half of the watershed. The Sand Plain region is a relatively flat sand plain in the central and eastern portions of the watershed and is the lowest area of land in the basin.

Bedrock consists of Silurian dolomites, sandstones, and shales, and of Ordovician limestones and shales (Map 2743B-3). Overburden, which varies in thickness up to 500 feet, consists of glacial till, glacio-fluvial kame terrace, kame, and outwash deposits, and lacustrine sands, silts, and clays (Map 2743B-4). Predominant surface deposits are associated with each of the four physiographic regions: till and outwash in the Escarpment Upland region, kame and ice-contact deposits in the Kame Hills region, till in the Ground Moraine region, and sand in the Sand Plain region.

The best aquifer in the bedrock is the Amabel dolomite, from which yields in excess of 100 gpm can be obtained. Dolomites of the underlying Fossil Hill Formation and the Cataract Group yield water adequate only for domestic and stock uses. Shales of the Queenston Formation, and limestones of the Trenton River Group are poor water-bearing formations and are not recommended for aquifer exploration.

Four significant aquifers are identified in the overburden (Map 2743B-5):

(1) a confined sand and gravel aquifer in the Nottawasaga bedrock valley ("Hockley Valley aquifer");
(2) a confined, deep, sand aquifer associated with lacustrine deposits at elevations between 400 and 500 feet ("Alliston sand aquifer");
(3) a confined sand aquifer near Thornton ("Thornton sand aquifer"); and
(4) an unconfined sand aquifer on the Lake Algonquin plain ("Lake Algonquin sand aquifer").

The gravel in the Hockley Valley aquifer is about 20 feet thick, but its precise extent in the valley is difficult to define. Downstream from Hockley, the gravel formation changes to sand. Yields as high as 100 gpm can be expected from the total thickness of sand and gravel.

The top of the Alliston sand aquifer is located close to an elevation of 500 feet. The piezometric surface elevation is generally between 730 and 785 feet, and most wells in this aquifer will flow when the collar elevations are below 750 feet. Yields from the sand can be as high as 700 gpm, and the formation is recommended for development by Alliston, Beeton, and Cookstown.

The top of the Thornton sand aquifer is close to an elevation of 850 feet, and wells in the formation have static water levels that are often more than 100 feet deep. Average yields from the formation are about 5 gpm, but higher yields may be obtained by total penetration of the sand, which is only about 10 feet thick.

The Lake Algonquin sand aquifer consists of the surface sands in the east-central sand plain in the basin. Yields from this aquifer are usually less than 5 gpm, but it is a consistently productive aquifer for domestic supplies when saturated thicknesses of 10 feet or more are encountered. The average thickness of the deposit is about 40 feet, although thicknesses up to 80 feet have been reported in some wells.

Successful domestic wells can be constructed in the till and surface kame and outwash deposits, but the locations of the water-yielding zones are unpredictable and yields are usually small.

Twenty-one piezometers were installed in seven nests in the basin (Map 2743B-2), and two shallow wells were equipped with water-level recorders to study water-level responses to rainfall. Based on measurements of water levels in the piezometers, vertical gradients in the till in the areas around the east-central sand plain are all downward. In the sand on the plain itself, there were no noticeable vertical gradients at all, suggesting mainly lateral flow in the surface sands.

The water-level data from two recording observation wells were used to study the effects of rainfall on water levels in the Lake Algonquin sand aquifer and in a sand lens underlying the till cover north of Cookstown. The water level in the sand on the Lake Algonquin plain was fairly sensitive to local rainfall in 1968, and showed small yearly water-level changes. However, the water level in the sand under the till was seemingly unaffected by rainfall during the summer of 1968, and the piezometric surface had a much larger annual amplitude of fluctuation. Based on only 16 months of record (Nov. 1968 to Feb. 1969), net recharge to ground-water storage during this time occurred from fall through to late spring, when water levels are generally at their annual high, and net discharge was effective from late spring to the following fall.

The main stream in the basin is the Nottawasaga River, which has three main tributaries: Innisfil Creek, the Boyne River, and Sheldon Creek. Innisfil Creek has one large tributary, Bailey Creek, and the Boyne River and Sheldon Creek have no significant branches. Innisfil Creek sub-basin is the largest, accounting for slightly more than one-third of the total drainage area of the basin. Sheldon Creek drainage area is the smallest as it drains only about seven per cent of the basin.

Streamflow data were collected from five recording stations and at 25 periodic-measurement locations throughout the basin (Map 2743B-2). Three of the five stations were installed during 1968 and provided only short-term records for the investigation. Data at the other two stations consisted of streamflow measurements since 1947 on the Nottawasaga River near Baxter, and since 1963 on Bailey Creek near Beeton. For purposes of discussion of general streamflow variability and frequencies, only data from the Baxter gauge were used.

Streamflow hydrographs for the Nottawasaga River at Baxter indicate highest annual flows during the spring months and lowest flows usually in July and August. The 21-year average flow out of the basin, as indicated by the Baxter gauge, was 322 cfs, which has been exceeded approximately 24 per cent of the time in this interval.

Estimates of annual seven-day low flows in all the main streams in the basin, for a recurrence interval of 10 years, are shown on Figure 24. Except for sections of the Nottawasaga River, all streams in the basin have annual seven-day low flows of less than 10 cfs. The low flows in the Nottawasaga River increase rapidly from less than 3 cfs at Glen Cross to more than 10 cfs as it flows past Hockley. Once on the sand plain, the seven-day low flows in the river are greater than 20 cfs throughout the rest of the basin.

A comparison of unit yields from different areas of the basin during low flows in 1968 indicated the largest yields to be from kame areas just east of the escarpment. Most of this yield is attributed to base flow, thus indicating the dependence of streamflow on ground water. The highest yield of 0.60 cfs per square mile was from the Sheldon Creek sub-basin, which is in the Kame Hills physiographic region. Generally, yields from this region were higher than from other physiographic regions in the basin. In the other three regions, the yields ranged from negligible to 0.16 cfs per square mile.

Of four linear correlations between annual precipitation and runoff, only one regression line has a relatively high coefficient of correlation (r=0.87). The equation is:

$$Q = 0.67\,(0.85P_0 + 0.15P_1) - 12.42$$

where Q = annual runoff from basin, in inches

P_0 = annual precipitation in the basin for the current year, in inches

P_1 = annual precipitation in the basin for the antecedent year, in inches

Three methods were used to estimate evapotranspiration (ET) during the 1968 water year: 1) the Thornthwaite method, 2) the procedure developed by Konstantinov, and 3) the water-balance method. The Konstantinov procedure is deemed to yield the most applicable results and was used in calculating the monthly hydrologic budgets for the 1968 water year. The annual budget is (all values in inches):

Precipitation		Total Runoff	ET	Changes in Storage and Underflow
33.2	=	12.7	+ 23.0	-2.5

and

Total Runoff		Direct Runoff		Ground-water Runoff
12.7	=	7.8	+	4.9

Precipitation during the 1968 water year was slightly above normal as compared to the normal precipitation at Beeton of 30.8 inches.

Thirty samples of ground water, eight of surface water and one of rain water were collected during 1968 for chemical analyses (Appendix B). Most waters in the basin are of calcium-bicarbonate type and are generally suitable for domestic and irrigation uses. Surface-water samples were characterized by high concentrations of total iron, and by little variability in chemical quality among the eight samples. Ground-water samples from shale bedrock usually contain high concentrations of sodium, and are generally softer than ground waters from limestone or overburden. Unexpectedly high chloride concentrations in waters from two shallow overburden wells have been attributed to pollution by road salt.

Five towns in the basin have municipal water-supply systems: Alliston, Beeton, Cookstown, Shelburne, and Tottenham. Alliston has the largest system, with a rated capacity of 1.2 million gpd, and Cookstown's system of 60,500 gpd is the smallest. Future ground-water development at all municipal sites appears to be favourable from aquifers which have not been fully developed to date.

Only four municipalities had sewage treatment systems in 1970: Alliston, Beeton, Shelburne, and Tottenham. The Alliston municipal system, consisting of secondary treatment, was the largest, with a capacity to handle 200,000 gpd, and the Beeton system was smallest at 96,000 gpd. Effluent from lagoons at Beeton and Tottenham was discharged to Beeton Creek, and Shelburne's effluent was discharged to a tributary of the Boyne River. A biological investigation of streams during 1968 indicated generally good water quality downstream from the Alliston system, but a definite degradation of water quality in the vicinity of effluent discharge from the Shelburne treatment lagoons. Salada Foods Limited at Alliston has a large private system rated at 750,000 gpd and discharges its effluent into a tributary of the Boyne River. During the biological survey the tributary was found to be impaired throughout its length, but the problem was rectified shortly after the survey.

Withdrawals for irrigation of tobacco, potatoes, and sod place heavy demands on stream water. The effects of these demands are most noticeable in the Innisfil Creek sub-basin where flows in Beeton and Bailey creeks, as well as in Innisfil Creek, have been reduced significantly. At times, flows in certain sections of some of the streams in the Innisfil Creek sub-basin have been reduced to zero.

An investigation of water use for irrigation in 1966 indicated that withdrawal from Nottawasaga River was largest, amounting to an estimated 106 million gallons during the irrigation period. Withdrawals from Innisfil Creek were estimated to be smallest, only 5 million gallons. Throughout the upper Nottawasaga River basin an estimated 80 million gallons of water from streams were used for irrigation of potatoes, 70 million gallons for tobacco, and 57 million gallons for sod.

During 1966, estimated daily withdrawals from the Nottawasaga and Boyne rivers, and from Beeton, Bailey, and Innisfil creeks, did not exceed the seven-day minimum flows in these streams for recurrence intervals of 3 and 10 years. However, all permittees did not extract water during the year. The total amounts of water allowed by OWRC permits for 1966 in Innisfil, Beeton, and Bailey creeks exceeded the seven-day low flows for return periods of both 10 and 3 years.

The availability and chemical quality of both surface and ground water in most parts of the basin are generally good. However, irrigation demands on stream water, together with water-supply and waste-disposal requirements for urban development, indicate a need for increased emphasis on water management in the upper Nottawasaga River basin. The biological aspects of water quality have not been studied in detail, but should be considered in conjunction with the management guidelines presented in this report.

In ground-water management, the following three points are made:

(1) control of flowing wells on the low, central, sand plain is desirable;

(2) precautions must be taken in areas of surface sands and gravels to prevent pollution of ground water by indiscriminant dumping of solid or liquid wastes;

(3) the management of aquifers in which municipal wells are constructed is necessary as more large-capacity wells are installed.

General concepts advocated for surface-water management are:

(1) stream-water development and use in the basin should include consideration of low flows in the streams to minimize the effects of withdrawals on natural stream functions and allow for sufficient flow for waste assimilation and dilution;

(2) the preservation of water quality and quantity in head-water streams and swamps is important, together with evaluations of the hydrologic and ecologic significance of swamps that occur on the Lake Algonquin sand plain;

(3) plans for use and management of stream water in the Innisfil Creek sub-basin should include evaluations of ground water as an alternative source for irrigation.

The interrelation between surface and ground water must be recognized in management planning. With more intensive development of ground water, there will be greater interference with streamflow. The timing and the degree of such interference will vary with the characteristics of the aquifers, the locations and amounts of ground-water withdrawals, and the proportion of the water that eventually returns to aquifers or streams. The effects of ground-water development on streamflow will likely be more pronounced in the Kame Hills and Sand Plain physiographic regions.

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APPENDIX A

Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

Only those wells of which direct mention is made in the report appear in this appendix. Logs for all other wells, shown on Map 2743B-1, are on file with the Division of Water Resources, OWRC.

Abbreviations Used

Blck	Black
Bldr	Boulder
Brwn	Brown
Con	Concession
Csnd	Coarse sand
Flw	Flowing
Fsnd	Fine sand
Grvl	Gravel
Hpan	Hardpan
H S E	Hurontario Street East
H S W	Hurontario Street West
Lmsn	Limestone
Msnd	Medium sand
Obdn	Overburden
Prdg	Previously dug
Prdr	Previously drilled
Qsnd	Quicksand
Shle	Shale
Snd	Sand
Stns	Stones
Tpsl	Topsoil
Twp	Township
Whit	White
Yllw	Yellow

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
					DUFFERIN COUNTY							
	Amaranth											
7		1	7	L. Marshall	10/61	4	90	8	4	50	Fresh	Tpsl 3; Brwn Clay Stns 16; Stns Grvl Clay 63; Lmsn 90. Water at 80.
8		1	6	C. Trimble	1/64	36	36	21	10	33	Fresh	Tpsl 3; Grvl Stns 32; Msnd Grvl 36. Water at 33.
	Melancthon											
296		1	1	Pawley	5/49	5	116	4	12	—	Fresh	Clay Stns 40; Lmsn 116. Water at 110.
340		3	3	R. Little	8/66	36	28	—	—	—	Fresh	Clay 2; Stns Clay 15; Clay Stns Shle 28. Water at 14.
	Mono											
455		1	32	Ontario Christian Assembly	9/65	5	250	140	12	165	Fresh	Clay Stns 6; Msnd 65; Grey Clay Stns 110; Msnd 120; Grey Clay Stns 145; Grey Lmsn 205; Red Shle 250. Water at 180, 240.

464		2	14	B. Coulter	10/62	—	54	38	6	40	Fresh	Prdg 23; Grvl Stns 50; Hpan 53; Grvl 54. Water at 54.
483		3	19	G. Donaldson	7/66	4	28	11	10	20	Fresh	Grvl 24; Lmsn 28. Water at 28.
529		5	25	J. Smart	7/62	4	35	Flw	10	20	Fresh	Brwn Clay Msnd 21; Grey Clay 33; Grvl 35. Water at 33.
531		5	32	R. Perryman	4/65	4	105	38	8	60	Fresh	Clay Msnd 50; Clay Grvl 62; Red Shle 105. Water at 75.
571	H S E	8	16	J. Storey	11/65	4	450	160	5	170	Fresh	Prdg 18; Blue Clay Grvl Stns 450; Grvl 475. Water at 450.
581	H S E	8	32	D. Woodley	5/67	30	30	15	2	—	Fresh	Brwn Clay Stns 29; Shle 30. Water at 15.
601	H S W	1	6	Mono Twp. School Area	10/58	4	93	28	5	60	Fresh	Clay Stns 10; Clay Msnd Bldr 45; Msnd 50; Red Shle 60; Blue Shle 93. Water at 80.
605	H S W	1	7	Edelbrook Lumber Co.	9/62	5	136	47	7	90	Fresh	Grvl 12; Msnd Bldr 78; Blue Shle 134; Grey Lmsn 136. Water at 135.
606	H S W	1	7	Edelbrook Lumber Co.	11/62	36	12	5	50	—	Fresh	Tpsl 2; Grvl 6; Csnd 11; Blue Clay 12. Water at 6.
614	H S W	1	11	E. Morgan	5/67	4	69	32	7	38	Fresh	Clay 17; Grvl 25; Lmsn 69. Water at 67.
615	H S W	1	12	J. Cruickshank	11/57	4	50	20	10	24	Fresh	Clay Bldr 35; Grey Lmsn 50. Water at 48.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	Mono											
616	H S W	1	14	F. Rayfield	10/49	4	60	27	25	31	Fresh	Clay Msnd Stns 40; Msnd 50; Lmsn 60. Water at 40, 55.
620	H S W	1	16	Mono Trustee School Board	10/50	4	120	15	6	50	Fresh	Clay Stns 30; Clay Msnd Stns 60, Brwn Lmsn 120. Water at 70, 110.
625	H S W	1	21	A. Mournham	3/57	6	93	Flw	—	—	Fresh	Msnd Grvl 56; Lmsn 93. Water at 93.
626	H S W	1	26	F. Buchanan	11/51	4	108	20	12	28	Fresh	Msnd Silt 5; Clay Msnd Stns 80; Brwn Lmsn 100; Whit Lmsn 108. Water at 90, 100.
627	H S W	1	27	H. Ruthledge	1/61	—	117	48	6	54	Fresh	Prdg 50; Csnd 70; Msnd Clay 90; Clay Grvl Stns 98; Lmsn 117. Water at 105.
628	H S W	1	28	H. Elgie	9/52	4	74	19	16	24	Fresh	Clay Stns 25; Clay Msnd 45; Qsnd 52; Brwn Lmsn 67, Whit Lmsn 74. Water at 60.

629	H S W	1	32	G. Yules	6/51	4	87	20	6	20	Fresh	Msnd 84; Blue Shle 87. Water at 87.
660	H S W	2	17	F. O. Thompson	4/46	4	50	10	20	10	Fresh	Yllw Clay 12; Grey Lmsn 50. Water at 50.
664	H S W	2	21	F. Thomas	12/65	4	56	4	25	14	Fresh	Brwn Clay Stns 26; Brwn Msnd Silt 36; Brwn Clay Stns Bldr 44; Lmsn 56. Water at 44.
665	H S W	2	24	H. J. Burton	8/63	4	60	Flw	—	—	Fresh	Blck Muck 2; Yllw Clay Msnd 20; Blue Clay Grvl Stns 50; Shle Grvl 60. Water at 55.
669	H S W	2	31	D. H. O.	2/65	5	102	16	20	20	Fresh	Tpsl 3; Msnd Stns 35; Hpan Bldr 48; Grvl 54; Brwn Lmsn 70; Grey Lmsn 93; Blue Shle 98; Red Shle 102. Water at 85.
671	H S W	2	32	G. Wissen	12/62	4	60	8	6	15	Fresh	Msnd 37; Clay Stns 47; Grvl Msnd 50; Blue Lmsn 60. Water at 47.
680	H S W	3	32	E. Erickson	10/62		88	20	18	25	Fresh	Prdg 18; Grvl 25; Grey Clay 40; Clay Msnd 50; Clay Stns 70; Brwn Lmsn 88. Water at 70, 85.
	Mulmur											
688	H S E	2	1	Twp. School Board	7/66	7	205	65	3	160	Fresh	Tpsl Clay 6; Grvl Bldr 50; Brwn Msnd 125; Yllw Clay 135; Qsnd 180; Msnd Grvl 194; Stns Grvl 197; Red Shle 205.
691	H S E	2	7	N. Beaton	10/65	36	22	17	3	19	Fresh	Tpsl 1; Msnd Clay 4; Msnd 14; Clay Bldr 16; Brwn Clay Stns Grvl 22. Water at 17.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	Mulmur											
712	H S E	4	2	W. Bowers	7/47	4	162	34	6	84	Fresh	Red Clay Stns 54; Qsnd 90; Red Clay Stns 98; Red Shle 162. Water at 140.
721	H S E	5	1	D. H. O.	3/63	4	242	50	8	60	Fresh	Clay Grvl Bldr 16; Msnd 74; Red Shle 180; Blue Lmsn 242. Water at 240.
725	H S E	5	8	J. M. Sadlier	12/65	5	165	45	2	90	Fresh	Msnd 10; Grey Clay Lmsn 45; Blue Shle 165. Water at 150.
778	H S W	1	2	C. F. Wood	9/57	4	65	30	3	50	Fresh	Lmsn Shle Clay 25; Lmsn 40; Red Shle 65. Water at 60.
780	H S W	1	4	S. J. Hopkins	11/67	7	211	90	14	92	Fresh	Tpsl 2; Hpan Bldr 67; Brwn Lmsn Shle 90; Grey Lmsn 158; Red Shle 211. Water at 87, 201.
782	H S W	1	5	Primrose School	11/50	6	100	28	6	1	Fresh	Clay 12; Lmsn 72; Blue Shle 87; Blue Shle 100. Water at 87.

798	H S W	2	10	Whitfield School	8/49	4	116	101	20	101	Fresh	Clay 60; Clay Stns Msnd 92; Msnd 98; Lmsn 116. Water at 110.
809	H S W	3	1	W. Bunston	9/50	4	80	18	—	80	Fresh	Tpsl 2; Hpan 8; Grvl 46; Lmsn 80. Water at 35.
	Shelburne Village											
844				Shelburne Village	11/49	6	53	—	—	—	—	Blck Muck 2; Brwn Clay 5; Clay Bldr 15; Clay 26; Clay Grvl 44; Clay Grvl 50; Shle 53. Water horizon not reported.
845				Shelburne Village	4/50	12	75	Flw	350	8	Fresh	Tpsl 3; Red Qsnd 8; Grey Qsnd 32; Grvl Stns 33; Lmsn 70; Lmsn 75. Water at 44.
						PEEL COUNTY						
	Albion											
471		8	24	H. J. Fraser	7/64	5	87	35	7	40	Fresh	Brwn Clay 6; Msnd Silt 80; Msnd 87. Water at 80.
488		9	26	S. Hicks	5/67	6	68	26	6	60	Fresh	Tpsl 1; Clay Msnd Stns 20; Blue Msnd Clay 53; Brwn Msnd 68. Water at 62.
489		9	27	Slav Catholic Club	8/59	5	76	11	25	20	Fresh	Brwn Tpsl Clay 10; Grvl 17; Clay Msnd 56; Msnd 76. Water at 56.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
						SIMCOE COUNTY						
	Adjala											
24		1	32	G. Dawson	11/62	30	45	30	3	40	Fresh	Clay Stns 40; Msnd 45. Water at 40.
92		3	21	J. Colbeck	10/64	36	10	6	3	8	Fresh	Tpsl 1; Tpsl Msnd 4; Grvl 10. Water at 7.
119		4	31	E. Hall	8/65	6	60	17	4	50	Fresh	Clay Bldr 19; Grey Shle 60. Water at 60.
184		7	32	J. Grundy	10/59	4	93	Flw	6	—	Fresh	Tpsl 1; Brwn Clay 6; Silt 34; Clay 59; Msnd 86; Msnd Grvl 93. Water at 93.
198		8	23	K. Bye	2/65	30	15	3	2	—	Fresh	Blck Tpsl 2; Fsnd 15. Water at 3.
266		8	16	O. W. R. C.	10/68	6	152	—	—	—	Fresh	Test Hole: Tpsl 1; Silt 42; Clay 78; Snd Grvl 81; Clay 133; Snd 152. Water at 5, 78.

	Essa											
262		9	1	O. W. R. C.	9/68	6	133	—	—	—	Fresh	Tpsl 1; Silt 26; Snd 29; Clay 37; Silt 44; Clay 130; Snd 133. Water at 9, 130.
263		5	5	O. W. R. C.	9/68	6	46	—	—	—	Fresh	Tpsl 1; Snd 33; Clay 41; Snd 46. Water at 17, 41.
264		1	8	O. W. R. C.	9/68	6	125	—	—	—	Fresh	Tpsl 1; Silt Snd Clay 70; Silt Clay Snd 125. Water at 25.
456		1	4	Alliston P.U.C.	10/67	6	348	—	—	—	—	Tpsl 1; Clay 9; Clay Grvl 22; Clay Silt Msnd 43; Clay Silt 166; Silt Clay 181; Clay Silt 244; Clay 343; Lmsn 348. Dry.
459		1	6	P. Kerr	10/66	30	44	32	1	42	Fresh	Msnd Clay 3; Brwn Clay 11; Blue Clay 22; Grvl 23; Blue Clay 43. Water at 22.
478		2	3	Alliston P.U.C.	10/49	6	275	—	—	—	—	Tpsl 2; Msnd Clay 10; Clay Msnd Grvl 145; Clay Grvl Msnd 152; Bldr Clay Grvl 194; Clay Msnd Grvl 266; Clay Bldr 274; Shle 275. Dry.
489		3	15	J. G. Breese	9/66	30	18	12	2	—	Fresh	Msnd 18.
506		4	1	B. Mayberry	4/62	4	75	5	3	70	Fresh	Clay Msnd Stns 1; Brwn Msnd 30; Grey Clay 57; Silt 64; Msnd 74; Grey Clay 75. Water at 74.
528		5	15	Baxter School	12/62	30	29	16	1	—	Fresh	Brwn Msnd 29. Water at 16.
542		6	1	H. Morrison	1/60	6	235	Flw	20	5	Fresh	Prdg 220; Clay 230; Grvl 235. Water at 230.
601		9	1	L. Cook	5/64	4	163	107	5	123	Fresh	Prdg 107; Brwn Clay Msnd 110; Fsnd 120; Msnd Csnd 127; Blue Clay 157; Clay Msnd 158; Msnd Fsnd 163. Water at 158.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	Essa											
628		10	10	P. Olaskey	12/60	22	27	10	4	—	Fresh	Prdg 15; Clay Msnd 27. Water at 10.
629		10	10	L. Valentine	3/67	4	115	36	8	41	Fresh	Clay Msnd Grvl 87; Msnd Silt 98; Msnd 115. Water at 98.
654		11	6	G. Graham	8/63	—	100	32	10	85	Fresh	Prdg 40; Msnd 52; Blue Clay Grvl Bldr 80; Grvl Silt 97; Msnd 100. Water at 97.
655		11	13	H. Stonehouse	9/64	—	78	57	10	68	Fresh	Prdg 58; Csnd Grvl 78. Water at 75.
656		11	14	W. Lockhart	6/57	4	195	30	6	38	Fresh	Clay Msnd Stns 38; Shle 54; Shle Qsnd 185; Fsnd 190; Msnd Fsnd 195. Water at 185.

692		11	20	J. Kloosterman	2/61	6	140	85	12	135	Fresh	Grvl Msnd 6; Blue Clay 37; Brwn Clay Msnd 128; Csnd 140. Water at 136.
	Cookstown Village											
356				Cookstown P.U.C.	5/59	5	272	Flw	10	26	Fresh	Tpsl 1; Grey Clay 14; Grey Clay Grvl 23; Clay Grvl Bldr 29; Fsnd 34; Clay Grvl 75; Hpan 80; Clay 89; Fsnd 91; Clay 92; Grvl 93; Clay 97; Clay Bldr 101; Clay 105; Fsnd Clay 111; Clay Bldr 113; Clay 130; Clay Msnd 139; Clay 206; Silt Msnd 212; Clay Grvl Bldr 272. Water at 89, 206.
	Innisfil											
863		1	2	F. Numberson	1/67	—	439	99	4	350	Fresh	Prdg 53; Msnd 60; Msnd Grvl Clay 75; Blue Clay 217; Clay 227; Blue Clay 287; Clay Csnd Grvl 320; Clay Silt Grvl 350; Grey Lmsn 439. Water at 350.
864		1	4	W. Dermott	4/63	30	75	40	1	—	Fresh	Brwn Tpsl 14; Grey Clay 73; Grey Msnd 75. Water at 75.
868		1	7	British American Oil	5/54	8	340	Flw	—	—	Fresh	Tpsl 4; Qsnd 150; Hpan Clay 215; Grvl Clay 220; Hpan Clay 297; Lmsn Shle 340. Water at 125, 220, 300, 320.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	Innisfil											
871		1	10	J. Maehara	9/64	4	314	Flw	—	—	Fresh	Blck Muck 3; Blue Clay Msnd 25; Fsnd 38; Csnd 50; Blue Clay 80; Clay Msnd 86; Grvl 89; Blue Clay 94; Msnd 98; Csnd 120; Blue Clay 138; Blue Clay Msnd 155; Blue Clay Grvl 226; Msnd 232; Fsnd Clay 240; Msnd 260; Blue Clay 310; Msnd 314. Water at 310.
872		1	12	K. Matchett	9/65	30	62	56	2	—	Fresh	Tpsl 2; Clay 12; Clay Stns 57; Grvl 62. Water at 58.
873		1	13	B. Constable	8/65	30	56	32	2	—	Fresh	Tpsl 2; Clay 24; Blue Clay Stns 47; Blue Clay Msnd 56. Water at 48.
874		1	14	H. Bell	2/64	30	56	40	1	—	Fresh	Tpsl 1; Grey Clay 18; Blue Clay 53; Msnd 56. Water at 54.
931		4	1	D. H. O.	6/60	7	388	—	—	—	—	Tpsl 1; Msnd 6; Clay 105; Qsnd 146; Clay 195, Hpan 218; Clay 388. Dry.

933		4	1	W. McCallum	4/66	30	60	48	2	—	Fresh	Tpsl 2; Clay Stns Msnd 58; Msnd 59; Clay Stns Msnd 60. Water at 58.
949		4	15	R. Browning	12/64	30	30	24	1	—	Fresh	Tpsl 1; Clay Msnd 24; Msnd 30. Water at 25.
1168		9	1	B. Blackstock	12/60	4	142	80	10	85	Fresh	Clay Stns 20; Hpan Bldr 130; Csnd 142. Water at 142.
1246		10	1	D. H. O.	3/63	4	181	125	10	135	Fresh	Brwn Clay Stns 60; Blue Clay 140; Qsnd 175; Csnd 181. Water at 175.
265	**Tecumseth**	9	1	O. W. R. C.	9/68	6	42	—	—	—	Fresh	Tpsl 1; Snd 42. Water at 14.
4052		1	4	D. Gobault	9/67	5	91	Flw	6	70	Fresh	Brwn Clay 15; Blue Clay 35; Msnd 37; Blue Clay Msnd 80; Fsnd 88; Msnd Clay 91. Water at 80.
4054		1	8	W. Volk	10/63	30	42	30	2	—	Fresh	Msnd 30; Grey Fsnd Clay 42. Water at 30.
4095		2	4	A. Jarvie	6/65	5	125	50	20	57	Fresh	Prdg 65; Msnd Grvl Clay 85; Blue Clay 100; Msnd Muck 108; Msnd 125. Water at 108.
4126		4	1	G. Maher	9/59	6	91	5	10	74	Fresh	Tpsl 1; Msnd 60; Fsnd 85; Msnd 91. Water at 91.
4143		5	6	R. Bailey	5/66	4	81	22	6	55	Fresh	Prdg 46; Grey Clay 80; Csnd 81. Water at 81.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	Tecumseth											
4150		5	18	I. Watson	11/62	30	30	14	2	—	Fresh	Brwn Clay Msnd 13; Grvl 16; Blue Clay Msnd Grvl 30. Water at 14.
4158		5	24	D. Fyles	3/67	30	37	6	1	—	Fresh	Tpsl 2; Brwn Clay 22; Blue Clay 37. Water at 33.
4173		6	24	Green	11/65	5	165	—	—	—	—	Prdg 18; Hpan 50; Grvl Clay 52; Hpan 90; Blue Clay 165. Dry.
4200		8	10	Beeton P.U.C.	11/66	6	177	Flw	50	50	Fresh	Blck Tpsl 2; Brwn Clay 8; Fsnd 10; Blue Clay 47; Hpan 51; Blue Clay 94; Blue Msnd 110; Blue Clay 166; Fsnd 177. Water at 8, 94, 166.
4211		8	22	H. J. Wilcox	7/66	30	61	39	2	—	Fresh	Tpsl 2; Brwn Clay 21; Blue Clay Stns 58; Grvl 61. Water at 59.
4213		9	8	J. English	3/62	30	25	18	2	—	Fresh	Msnd 25. Water at 18.

4218		9	24	E. Edney	10/63	30	51	31	2	—	Fresh	Tpsl 2; Clay 24; Clay Msnd Stns 41; Grvl 42; Clay 51. Water at 41.
4225		10	23	W. Halbert	8/62	4	330	75	2	320	Fresh	Prdg 20; Blue Clay 60; Fsnd 62; Blue Clay Silt 326; Msnd Grvl Clay 330. Water at 330.
4231		11	16	I. Varcoe	10/61	4	320	Flw	1	—	Fresh	Tpsl 16; Blue Clay 235; Grvl Msnd Clay 255; Brwn Shle 320. Water at 245.
4238		12	5	Alliston P.U.C.	8/67	4	264	Flw	150	8	Fresh	Msnd 4; Fsnd Csnd Grvl 58; Fsnd Grvl Clay 80; Grey Clay Silt 162; Grey Clay Silt Grvl 200; Fsnd Grvl Clay 260; Shle 264. Water at 200.
4242		12	24	B. Beeston	7/65	30	46	32	2	—	Fresh	Tpsl 2; Fsnd 8; Grey Clay Stns 46. Water at 7, 42.
4271		14	4	Alliston P.U.C.	5/61	2	272	22	20	27	Fresh	Msnd 6; Brwn Clay 8; Fsnd Grvl Clay 72; Blue Clay Silt 116; Clay Msnd Grvl 246; Clay Msnd Bldr 259; Clay Msnd 270; Lmsn 272. Water at 72.
4272		14	4	Alliston P.U.C.	12/61	2	313	10	30	32	Fresh	Tpsl 1; Fsnd 6; Msnd Grvl 8; Fsnd Clay 68; Msnd Silt 146; Fsnd Clay 178; Msnd Grvl Clay 206; Grvl Msnd 234; Msnd Silt Grvl 313. Water horizon not reported.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	Tecumseth											
4278		14	4	Alliston P.U.C.	12/61	19	269	14	664	177	Fresh	Brwn Msnd 5; Brwn Msnd Clay 47; Grvl Msnd Clay 73; Blue Clay 170; Clay Stns 183; Msnd Grvl Clay 188; Clay Stns Grvl 213; Msnd Grvl 231; Grvl Clay 238; Msnd Grvl 269. Water at 47, 183.
4288		15	10	D. Nicols	6/65	4	180	Flw	4	70	Fresh	Msnd 12; Grvl 14; Msnd Grvl Bldr 24; Grey Clay 98; Clay Silt Msnd 180. Water at 98.
4298		15	7	Swenson Feeds	9/63	30	52	45	5	—	Fresh	Msnd 52. Water at 45.
4304		14	23	Town of Cookstown	6/58	2	219	Flw	30	4	Fresh	Tpsl 1; Grey Clay 19; Silt 21; Clay Silt 46; Grvl 47; Clay 101; Silt 105; Clay 174; Clay Silt 182; Grvl Clay 186; Clay Grvl 190; Clay Silt 205; Clay Grvl 208; Grvl 216; Clay Grvl 219. Water at 208.

	Tottenham Village											
4583				Village of Tottenham	9/62	3	304	16	80	32	Fresh	Brwn Clay Bldr 23; Brwn Fsnd 33; Blue Clay 55; Fsnd 57; Blue Clay Stns Silt 106; Msnd 107; Blue Clay 212; Silt 213; Hpan 243; Msnd Grvl Clay 294; Clay Stns 302; Blue Shle 304. Water at 23, 55, 106, 243.
	Tosorontio											
4522		1	5	J. Boyd	10/67	30	55	10	2	—	Fresh	Msnd 3; Clay Stns 20; Msnd 55. Water at 45.
4533		2	1	F. Little	4/65	30	32	25	2	30	Fresh	Tpsl 2; Brwn Clay Bldr 7; Brwn Clay 19; Hpan 27; Grvl 32. Water at 27.
4557		2	1	Alliston P.U.C.	7/59	5	—	—	—	—	—	Tpsl 1; Msnd Silt Clay 14; Clay Grvl 31; Clay Grvl Bldr 35; Clay 102; Grvl Bldr 108; Clay 156; Clay Silt 167; Msnd Grvl 169; Clay 181; Clay Bldr 195; Clay 214; Clay Grvl Bldr 222; Clay Silt 230; Clay 255; Silt 263; Clay Msnd Silt 278; Shle 280. Dry.
4559		6	1	J. Hephin	9/59	4	306	120	4	180	Fresh	Tpsl 1; Bldr Clay 80; Blue Clay 170; Silt 270; Clay 301; Msnd Grvl Clay 306. Water at 306.

Appendix A. Records of Selected Water Wells in the Upper Nottawasaga River Drainage Basin

(Locations of numbered wells are shown on Map 2743B-1)

Well No.	Location			Recorded Owner	Date of Completion	Well Diameter (inches)	Well Depth (feet)	Static Level (feet)	Pumping Rate (gpm)	Pumping level (feet)	Quality	Log and Remarks (Depths to which formation extends below the surface are given in feet)
	Township	Con	Lot									
	West Gwillimbury											
260		11	9	O. W. R. C.	9/68	6	127	—	—	—	—	Tpsl 2; Snd 24; Silt Snd Clay 127. Water at 4.
261		12	4	O. W. R. C.	9/68	6	40	—	—	—	—	Tpsl 1; Snd 35; Clay Silt 40. Water at 8.
5257		7	1	J. King	5/64	4	192	14	6	70	Fresh	Grey Clay 60; Grvl 87; Blue Clay 185; Whit Msnd 192. Water at 185.
5311		10	3	N. Hamilton	9/66	6	340	150	7	175	Fresh	Tpsl 1; Clay Stns 5; Grey Clay Msnd 52; Clay Grvl 54; Clay Msnd 125; Fsnd 127; Blue Clay 155; Grey Clay 335; Msnd Grvl 340. Water at 335.
5317		11	1	W. Bell	12/59	30	41	31	—	—	—	Brwn Clay 6; Csnd 31; Blue Clay 41. Water at 31.
5318		11	3	M. Jeffels	12/59	30	20	9	1	—	Fresh	Brwn Clay Msnd 4; Msnd 8; Grvl 10; Brwn Clay Grvl 20. Water at 9.

5349		13	3	J. Habaruk	7/65	7	294	Flw	30	9	Fresh	Blck Tpsl 3; Qsnd 76; Grey Clay 165; Grvl 241; Sndstone 294. Water at 294.

APPENDIX B

Chemical Analyses of Waters in the Upper Nottawasaga River Drainage Basin
1968

Appendix B. Chemical Analyses of Water in the Upper Nottawasaga River Drainage Basin, 1968

(Locations of water sampling points are shown on Map 2743B-6)

Source and Number	Location	Date Sampled	pH	Ionic Concentrations (ppm)										Total Alkalinity as $CaCO_3$ (ppm)	Total Hardness as $CaCO_3$ (ppm)	Total Dissolved Solids (ppm)	Specific Conductance (micromhos) at 25°C
				Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate				
Rainwater	Essa. Twp. XI - 6	23/8/68	8.0	9	1	0.6	0.2	26	4	1	0.15	0	0.04	21	24	58	—
Well 7	Amaranth Twp. I - 7	16/8/68	7.8	65	33	7	2	263	85	1	0.70	1.3	0.09	216	300	374	570
Well 8	Amaranth Twp. I - 6	20/8/68	7.6	129	35	8	2	406	58	28	0.10	0	21	333	470	706	1006
Well 92	Adjala Twp. III - 21	21/8/68	7.4	125	14	10	1.6	390	30	24	0.20	0	1.6	320	370	426	714
Well 119	Adjala Twp. IV - 31	21/8/68	7.8	28	8	150	13	330	20	115	0.10	0.8	0.41	271	106	502	914
Well 198	Adjala Twp. VIII - 23	21/8/68	7.4	71	19	68	1.2	358	0	57	6.60	0.3	0.04	294	256	430	714
Well 340	Melancthon Twp. III - 3	20/8/68	7.6	74	51	16	13	413	31	43	0.10	0.4	0.37	339	398	492	803
Well 459	Essa Twp. I - 6	19/8/68	7.6	116	9	5	1	262	43	9	0.20	0.1	7.6	215	330	418	640
Well 464	Mono Twp. II - 14	20/8/68	7.6	96	19	3	1	343	28	6	3.0	0	0.01	281	320	354	570

Well 483	Mono Twp. III - 19	20/8/68	7.7	70	17	3	2	265	18	3	0.20	0	0.02	217	246	272	451
Well 489	Essa Twp. III - 15	19/8/68	8.2	13	8	98	1	248	0	31	0.65	0.3	0.03	203	64	306	462
Well 528	Essa Twp. V - 15	23/8/68	7.3	151	13	12	0.8	297	36	116	0.10	0	2.4	244	434	650	904
Well 529	Mono Twp. V - 25	20/8/68	7.7	69	12	2	1	273	17	3	0.05	0.1	0.84	224	260	396	470
Well 542	Essa Twp. VI - 1	16/8/68	8.1	20	13	24	0.8	185	1	2	0.45	—	0.50	152	104	160	280
Well 571	Mono Twp. HSE VIII - 16	20/8/68	7.9	27	19	46	2	233	13	33	1.20	0.2	0.01	191	148	276	488
Well 606	Mono Twp. HSW I - 7	20/8/68	7.6	122	18	8	1	296	47	54	0.05	0	1.8	243	380	538	757
Well 627	Mono Twp. HSW I - 27	20/8/68	7.7	57	18	3	1	241	21	2	3.0	0.1	0.02	198	220	262	408
Well 628	Essa Twp. X - 10	20/8/68	7.9	40	21	16	1	245	11	2	1.10	0.1	0.10	201	186	270	368
Well 655	Essa Twp. XI - 13	20/8/68	7.7	82	18	4	1	297	32	2	0.40	0	0.03	244	282	278	503
Well 691	Mulmur Twp. HSE II - 7	20/8/68	7.7	87	12	2	2	262	26	3	0.15	0	1.1	215	268	332	493
Well 725	Mulmur Twp. HSE V - 8	20/8/68	7.9	42	15	102	11	217	105	83	0.15	0.7	0.01	178	166	698	826
Well 949	Innisfil Twp. IV - 15	19/8/68	8.0	43	17	148	8	255	3	226	1.60	0.7	0.02	209	178	616	1130

Appendix B. Chemical Analyses of Water in the Upper Nottawasaga River Drainage Basin, 1968

(Locations of water sampling points are shown on Map 2743B-6)

Source and Number	Location	Date Sampled	pH	Ionic Concentrations (ppm)										Total Alkalinity as CaCO3 (ppm)	Total Hardness as CaCO3 (ppm)	Total Dissolved Solids (ppm)	Specific Conductance (micromhos) at 25°C
				Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Sulphate	Chloride	Total Iron	Fluoride	Nitrate				
Well 4054	Tecumseth Twp. I - 8	19/8/68	7.6	106	12	6	13	328	25	12	0.15	0.1	2.77	269	316	414	640
Well 4126	Tecumseth Twp. IV - 1	20/8/68	7.6	110	15	32	1	340	29	31	0.15	0	5.04	279	334	466	743
Well 4150	Tecumseth Twp. V - 18	20/8/68	7.4	134	22	30	22	444	86	15	0.05	0	7.8	364	368	586	938
Well 4231	Tecumseth Twp. XI - 16	20/8/68	7.6	99	35	5	1	302	63	14	0.25	0.1	0.17	248	344	434	638
Well 4271	Tecumseth Twp. XIV - 4	21/8/68	7.8	31	20	23	1.5	218	2	19	0.25	0.3	0.01	179	162	236	391
Well 4522	Tosorontio Twp. I - 5	21/8/68	7.4	102	8	4	1.3	316	36	11	0.70	0	0.66	259	290	362	578
Well 5318	West Gwillimbury Twp. XI - 3	20/8/68	7.7	78	20	12	20	311	74	32	0.15	0.1	0.19	255	360	502	766
Well A	Adjala Twp. I - 7	20/8/68	7.6	99	9	3	1	282	36	6	0.1	0	1.19	231	284	342	524
Well B	West Gwillimbury Twp. XII - 9	20/8/68	7.6	114	17	25	1	265	17	105	0.05	0	4.17	217	356	594	832

Stream 1	Nottawasaga River	17/7/68	8.2	71	15	7	1.9	255	24	9	1.30	0.2	0.69	209	240	280	458
Stream 2	Nottawasaga River	17/7/68	8.3	69	15	6	1.4	249	23	7	1.35	0.1	0.78	204	236	284	461
Stream 12	Boyne River	18/7/68	8.3	56	16	5	1.6	226	18	6	1.48	0.1	0.26	185	208	276	396
Stream 14	Boyne River	18/7/68	8.3	65	16	5	1.2	245	14	9	0.66	0.2	0.92	203	228	260	432
Stream 18	Innisfil Creek	17/7/68	8.2	69	15	9	2.0	271	27	12	4.8	0.1	0.37	222	260	328	507
Stream 23	Bailey Creek	19/7/68	8.4	73	13	8	20	249	26	11	1.8	0.1	0.32	206	236	310	464
Stream 30	Sheldon Creek	17/7/68	8.6	61	16	3	0.9	226	15	2	0.35	0.1	1.5	187	218	256	400
Stream 33	Nottawasaga River	17/7/68	8.5	64	19	4	1.0	258	15	5	0.35	0.1	1.0	212	240	270	441

APPENDIX C

Nomograph for Calculating PE_x at Beeton

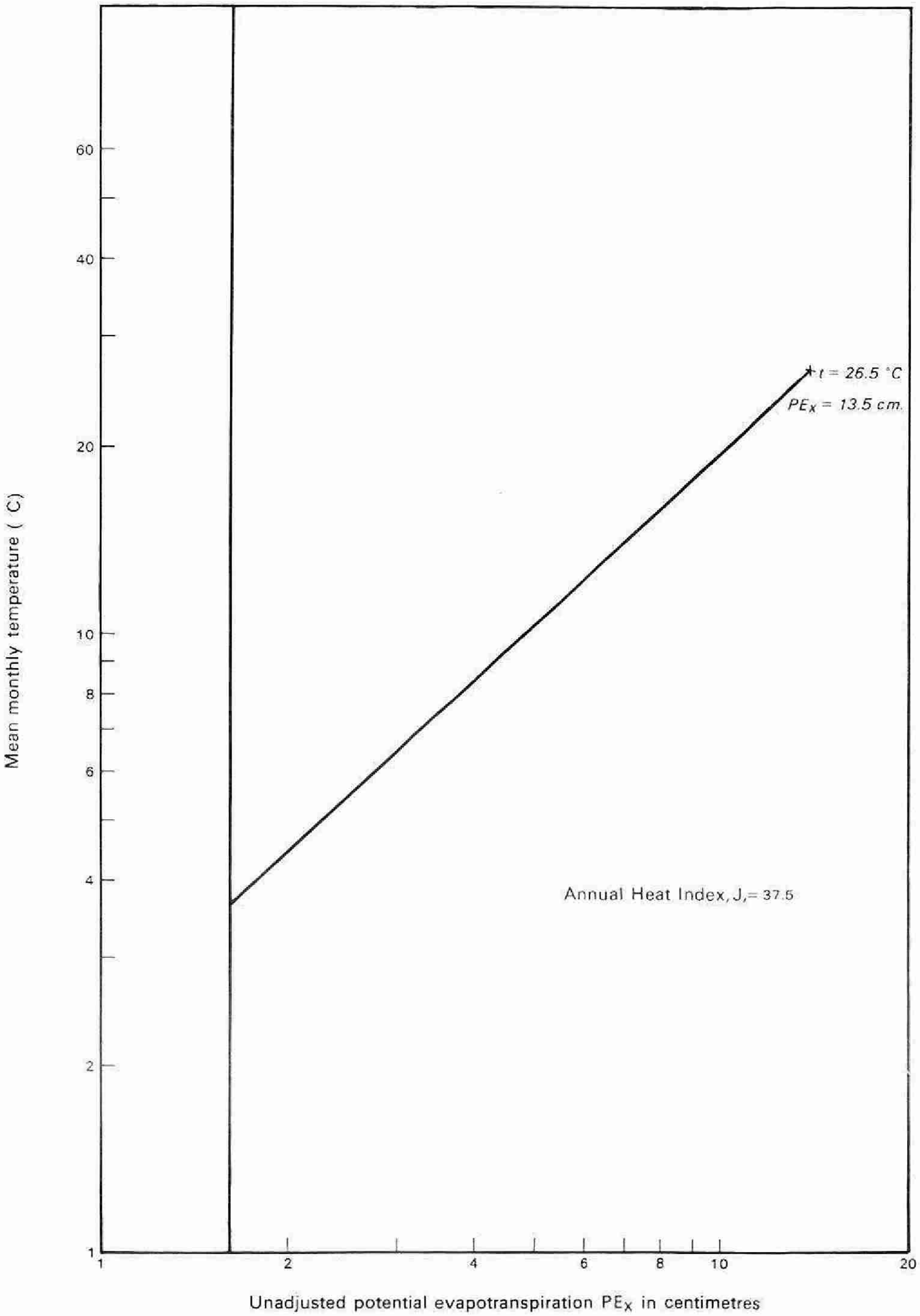

Figure 39. Nomograph for calculating PE$_X$ at Beeton (diagram after Thornthwaite, 1948).

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